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ENVIRONMENTAL APPLICATION OF REMOTE SENSING METHODS TO COASTAL ZONE LAND USE AND MARINE RESOURCE MANAGEMENT: FINAL REPORT

by

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ENVIRONMENTAL APPLICATION OF REMOTE SENSING METHODS TO COASTAL ZONE LAND USE AND MARINE RESOURCE MANAGEMENT: FINAL REPORT

INTRODUCTION

The potential of remote sensing both as a source of data and as the basis for an information system for resource analysis and management within the coastal zone has been the primary focus of this investigation. Three principal objectives* were initially defined:

1. To identify the management and planning agencies with responsibilities within the coastal zone; to investigate their present data base for planning and managing resources and to assess the potential of remote sensing as a complement to or supplement for this base. A subobjective was to study the cost effectiveness of remote sensing as an alternative data base.

2. To structure a demonstration pilot project wherein remote sensing of the environment would play a role in resource allocation and management within the coastal zone.

3. To evaluate the possibilities of assessing the environmental impact of land use alternatives by using the land use classification of the Geographic Applications Program of the USGS.

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*In support of these objectives the Central Atlantic Coastal Zone (CATCOZONE) was defined, and a high altitude aircraft photographic mission was planned with NASA, coordinated by the Geographic Applications Program of the USGS and flown in September, 1970 (Fig. 1). Mission 144 provided a photographic data base at various photometric scales using several combinations of film emulsions and filters. With this comprehensive photographic coverage as a base NASA established the Central Atlantic Regional Ecological Test Site (CARETS) in 1971 as one of the ERTS A test sites so as to include all of CATCOZONE north of the Virginia border.

The first objective of the research, with the exception of the cost effective study, was the subject of the initial report of the Coastal Zone Task Force (Goodell, et al, 1971). They found 1) that remote sensing could provide a unique data base which could supplement and complement some data sources currently used by state agencies, 2) that the data from remote sensing should be formated in a manner compatible to present decision-making, 3) that any function of planning or management which required earth surface observation holds the largest potential for remote sensing and that the function of regulation is second, and 4) that although several photometric scales, film emulsions and frequencies of observation would be required to satisfy all data requirements, black-and-white film at a scale of about 1:20,000 would meet most requirements.

The second and third objectives of the investigation are the subject of this report. CATCOZONE originally comprised more than 100,000 km^2 of the eastern seaboard. A smaller, more politically homogeneous area was desired for the demonstration project. In consultation with the Geographic Applications Program, an area of southeastern Virginia was selected and the demonstration project was developed around the growing public requirement for developing methodology by which the forecast of the probable environmental impact of resource allocation, especially land use, can be made. This is becoming one of the most important functions of the planner at all levels of public administration (Haskell, 1971; Johnson and Kerri,1971). The complexity of that task is enormous inasmuch as the linkages between the cause-and-effect relationships of a cultural process and environmental response are unusually complicated. In addition, the dynamics of the air, water, land and ecological systems which control environmental response are little understood and therefore scarcely predictable.

This report sets forth the criteria and the initial conceptualization for a computer based model for the forecasting the environmental consequences of resource allocations involving land use decision. Its ultimate efficiency will rest on the accuracy of the algorithms which link land use to a specific environmental impact and on the identification of the synergistic effects of these impacts as multiplied. It uses two major data sources: land use data as identified principally by remote sensing, and dynamic climatological data to be developed from the National Weather Records Center of NOAA.

The demonstration project suggests the establishment of RICHEL, an environmental laboratory, wherein the impact algorithms initially used in forecasting could be verified by field data so that the precision of the algorithms could be refined.

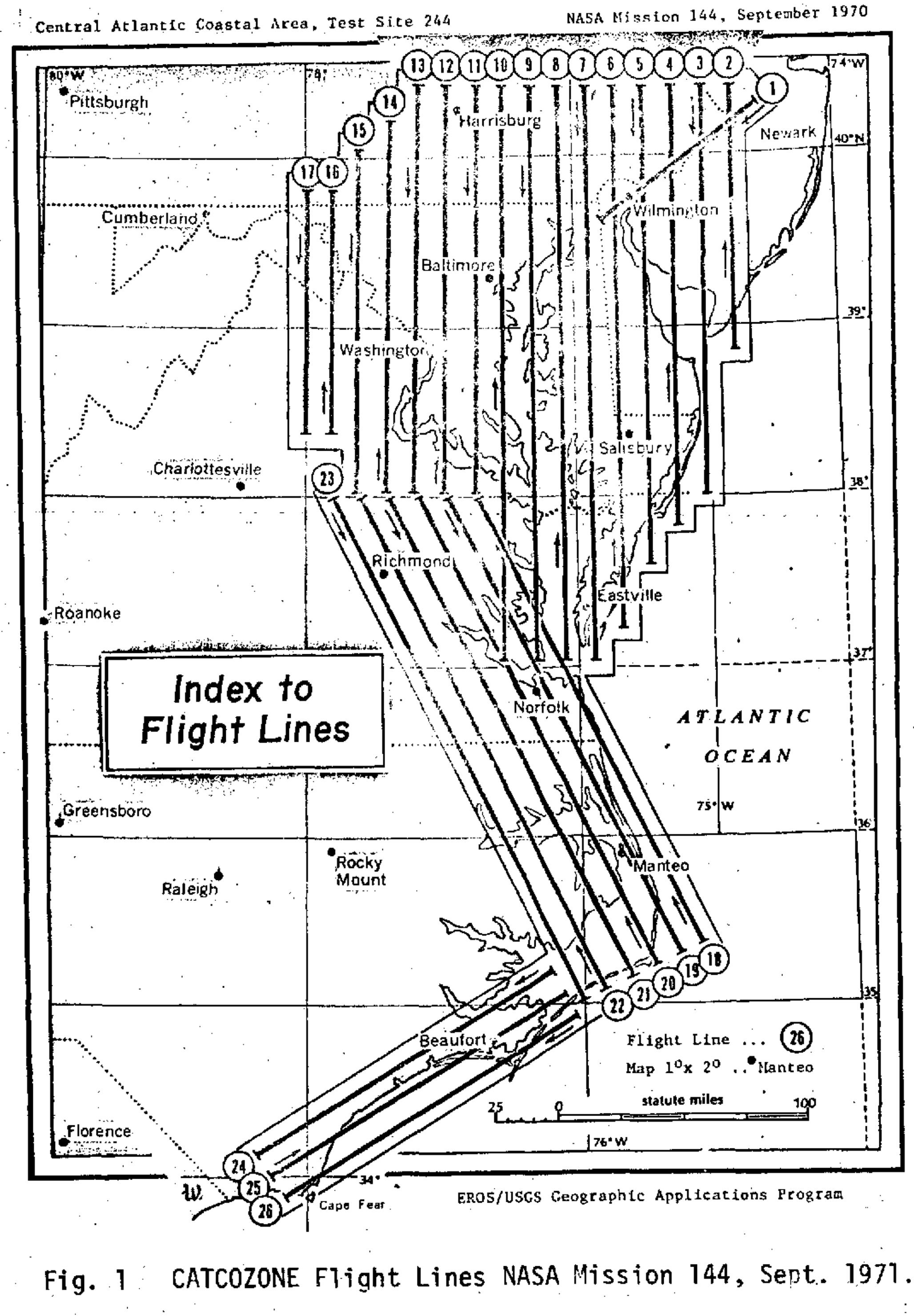


Fig. 1 CATCOZONE Flight Lines NASA Mission 144, Sept. 1971.

RICHEL

The Richmond-Cape Henry Environmental Laboratory (RICHEL) in southeastern Virginia is composed of 17 counties, 14 independent cities and 21 incorporated towns arranged into four planning districts (Fig. 2, Table 1). It comprises just over 6,834 mi.^{2} (17,715.14 km^2) with a 1970 population of 1,797,053; 38.66% that of the Commonwealth. Population densities range from less than 20 per mi.^{2} in Surry County to more than 6,500 per mi.^{2} in the City of Richmond (Table 1).

Ideally an environmental laboratory should have "natural" limits: a river basin or estuary, an air shed, or a biotope. However, much of the information on cultural environmental impact is only available as data sets aggregated by political subdivision, usually county, and not easily disaggregated for reassembly. More important, the ultimate use of the laboratory would be to guide planning strategy and to influence public policy so as to diminish environmental degradation. Both planning and policy are framed and exercised within political boundaries. Therefore, RICHEL was assembled by aggregating planning districts so as to include the drainage basin of the estuary of the lower James River (Fig. 3). There are a number of features about RICHEL which make it an appropriate choice for an environmental model:

1. It comprises the southern terminous of Virginia's Urban Corridor (Howard, et al, 1970) which is in turn an extension of Megalopolis (Gottman, 1961; Fig. 4). Between 1960 and 1970 the population within RICHEL expanded 1.8% per year with five

of its counties and independent cities experiencing annual growth rates in excess of 4% (Appendix G)! These rates of population growth are expected to decrease only slightly through the year 2000.

2. It contains the estuary of the James River and the southern end of Chesapeake Bay; two proposed scenic rivers, segments of the Chickahominy and Appomattox; the northern section of the Great Dismal Swamp; and two national wildlife refuges, Back Bay on the coast below Cape Henry and Presquile north of Hopewell. Environmental stresses in these once pristine areas are becoming acute: (a) while an estimated 75% of the shoreline of the James estuary remains undeveloped, short segments of the remainder are so highly polluted by municipal and industrial effluents that it is now considered a "working" estuary, (b) falling water tables from over-pumped ground water reservoirs coupled with canals dug for agribusiness drainage, boating, and commerce have caused significant loss of habitats in the Great Dismal Swamp, and (c) pressures for dredge-and-fill, encroaching urbanization, recreational demands, and future water impoundments are growing threats to the scenic rivers and the wildlife refuges.

3. Severe air pollution exists from Norfolk to Hampton in the east from Hopewell to Richmond in the west. The sources of the effluents are not only the usual industrial-municipal emissions but also more than 16 sawmill beehive-burners between the James River and the North Carolina border. In addition, in the spring and fall to the south and west of the estuary agricultural burning and forest fires make significant contributions to the particulate loading in the air.

4. Within 20 miles of Norfolk there are seven major airfields three of which (Langley AFB, NAS Norfolk, and NAS Oceana) have heavy jet traffic and three others (Patrick Henry, Norfolk Municipal and Felker AAB) have intermediate levels of traffic. Byrd Field, 60 miles northwest of Norfolk just east of Richmond, is an international airport with heavy jet traffic. Several of these are planning major expansions.

5. The Norfolk-Newport News-Hampton Roads port facilities is second to New York among east coast ports with both military and civilian shipping and ship building. Industrial, transportation, and power-generating supporting facilities are in proportion with railroad terminal facilities extremely heavy in order to handle coal, the chief bulk commodity export in the world's largest coal port. The principal import is oil with eleven major oil companies operating terminals. Navigation west of Norfolk on the James estuary is possible to the fall line at Richmond in a 25 ft. channel completed in 1947.

There are proposals under consideration by the U.S. Army Corps of Engineers to increase the channel depth to 35 ft. (U.S. Army Corps of Engineers, 1962a). This could bring significant changes in land use patterns with resulting environmental impact along the entire estuary.

6. Hydrology in RICHEL is a critical consideration in land use planning. Both the James River and its estuary are subject to periodic flooding (flood crests of more than 24 ft. have occurred in Richmond once every 20 yrs. since 1771) as are the coastal areas from Newport News to Cape Henry (VDCED, 1971). Even if intensive precipition occurs the municipal sanitary and storm drainage systems of Norfolk and Richmond which share common facilities are overwhelmed resulting in raw sewage outfalls in the James River and in Chesapeake Bay. In addition the coastal areas of RICHEL which enjoyed more than 10 ft. of artesian water standing at the surface 50 years ago is now water-poor. Surface reservoirs are becoming eutrophic as urbanization encroaches on their water sheds and the subsurface aquifers are becoming increasingly depleted by overpumping.

7. Severe beach erosion problems exist in Virginia Beach due to storm drainage and tidal flooding during hurricanes. In 1953 the city completed a program of artificial beach restoration and the Corps of Engineers nourishes the beach with sand to maintain a 100 ft. berm width at an elevation of 7 ft. above low water. The initial restoration required 1.253×10^6 cu. yds. of sand taken from salt marshes and tidal creeks near Rudee Inlet. It is estimated that 42×10^3 cu. yds. will be required annually for nourishment to be furnished from similar areas (U.S. Army Corps of Engineers, 1962b). Salt marshes have extremely high biological productivity.

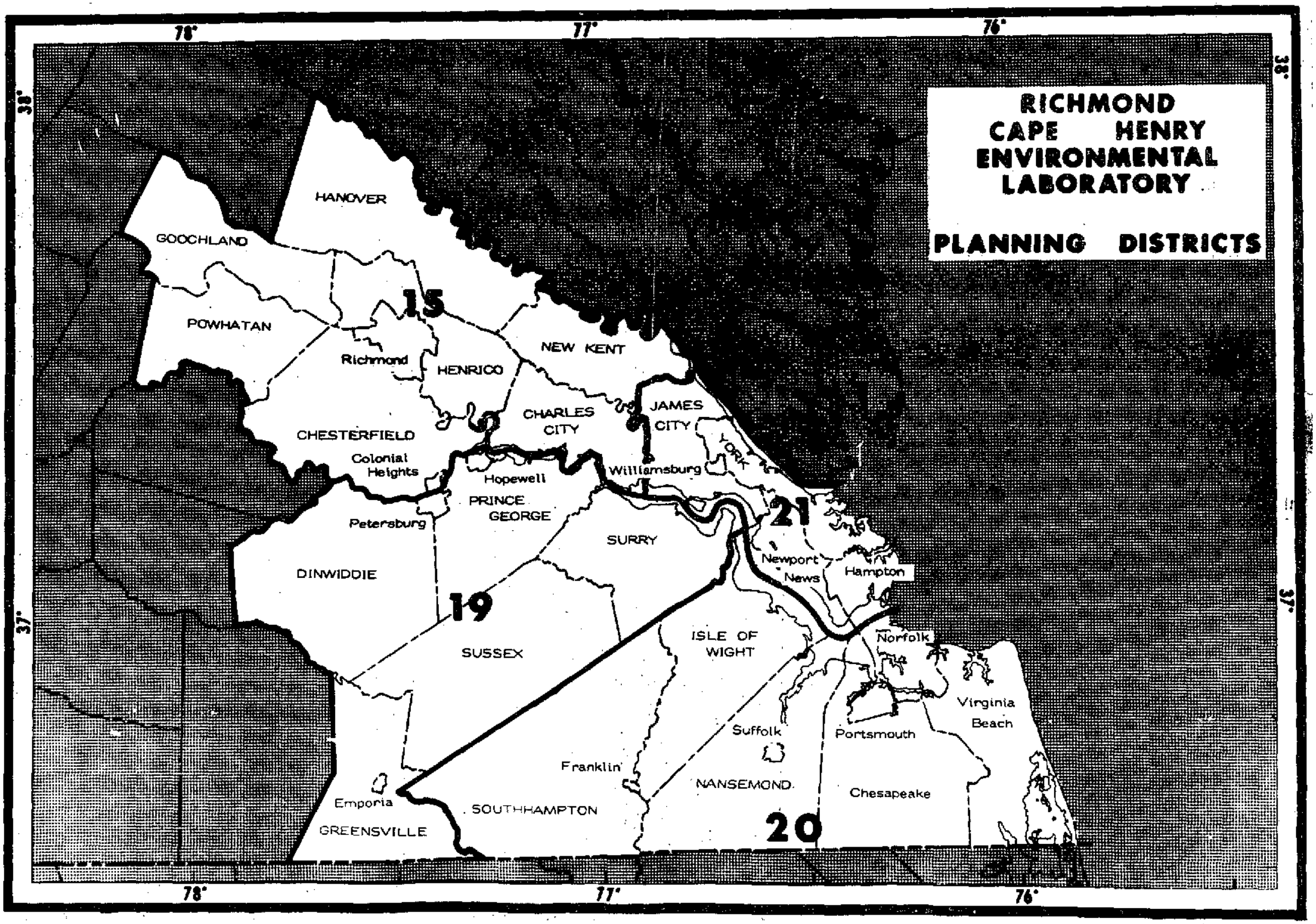


Fig. 2 The Richmond-Cape Henry Environmental Laboratory (RICHEL)

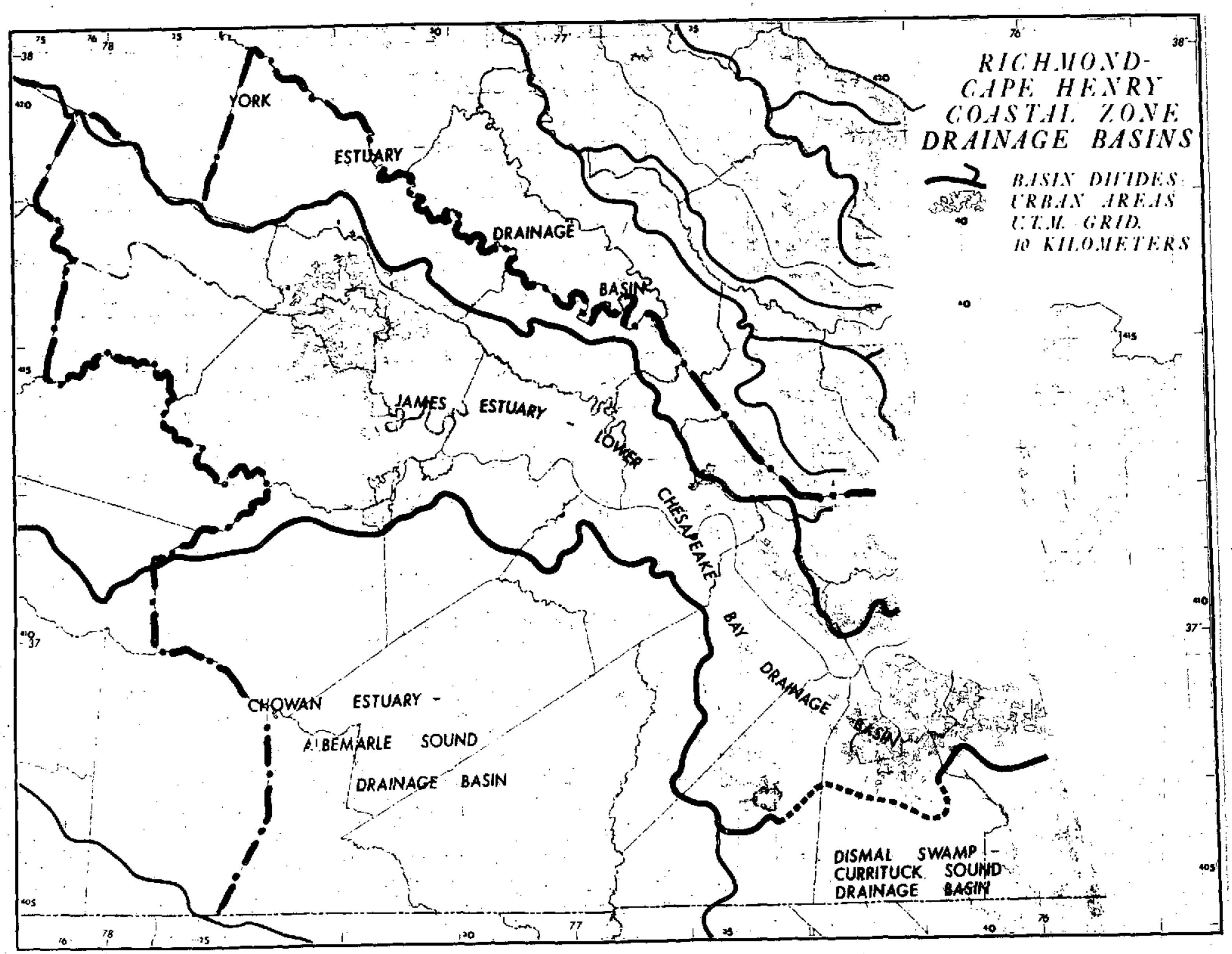


Fig. 3 RICHEL Drainage Basins

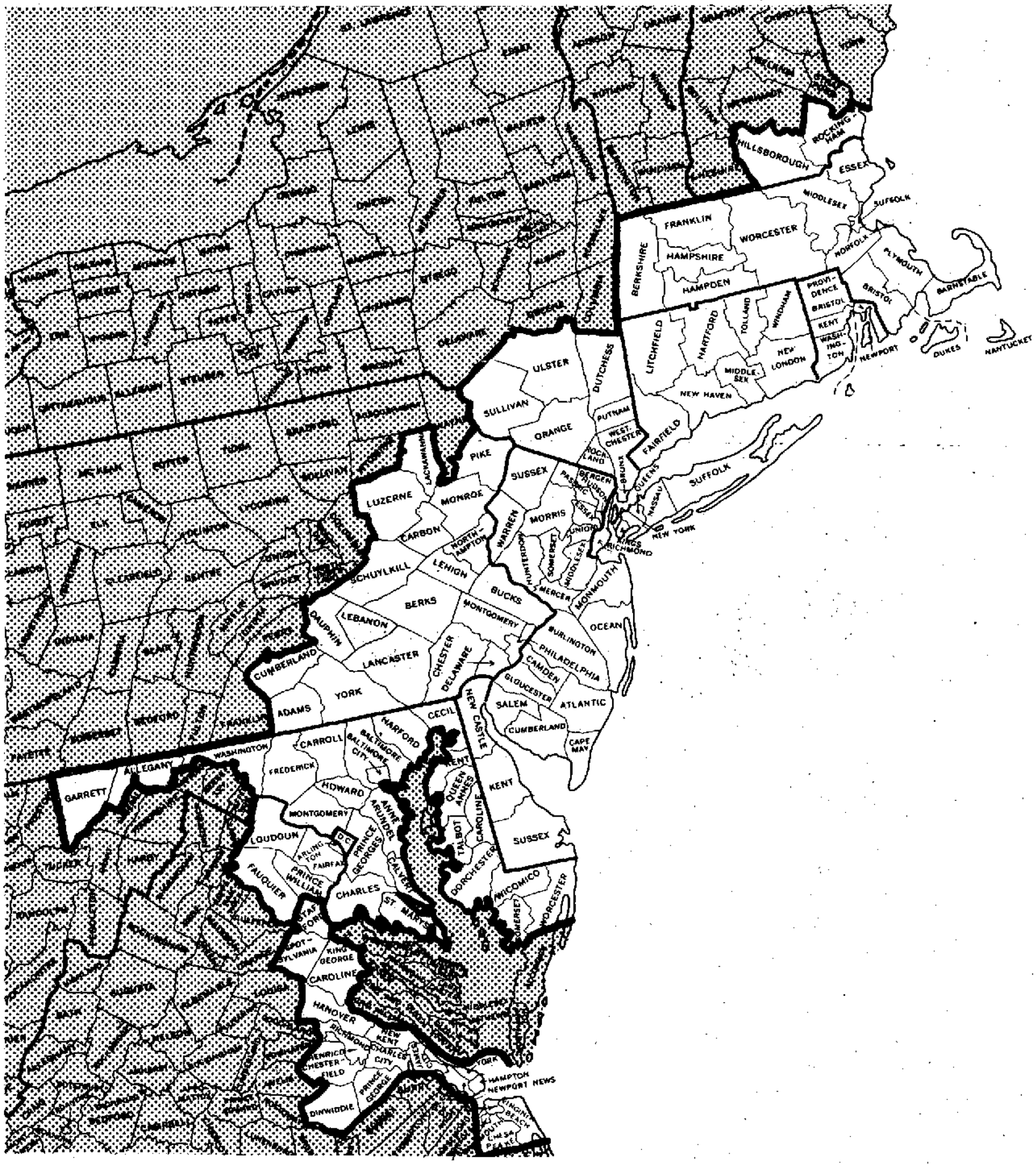


Fig. 4 Northeast Corridor in 1960 as conceived by Gottmann in Megalopolis and Virginia's Urban Corridor ten years later

THE MODEL

Conceptual Base

Efforts to systemize the data on which decisions affecting the environment are made have resulted in matrix check-lists (Leopold, et al, 1971; Sorensen, 1971) which are helpful in delineating linkages but which are of limited value in predicting the magnitude of effects. Attempts at physical, conceptual, and mathematical modeling are of more value. These require an understanding of both the characteristics and dynamics of the environment. Models which have been attempted to date are either simplified holistic ecosystems models (Odum, 1971), simplfied models of segments of ecosystems (Van Dyne, 1969), portions of the physical environment (Disano, 1968; Crawford and Linsley, 1966; Bruce and Hetling, 1970; Feigner and Harris, 1970) or simplified relationships between land use and resource allocations and environmental impact (Toebes, 1969; Holton and Lopez, 1971; Roberts, et al, 1970; Chen, 1970; McFadden and Armstrong, 1970).

The model which is proposed uses the hydrologic cycle as a framework for the analysis by which the environmental impact of resource allocation in terms of land use may be assessed.

The hydrological cycle was selected for several reasons: 1) it offers a holistic integrative focus that bears on all segments of the model, 2) its dynamics are orders of magnitude faster than the dynamics of land use, yet 3) demonstrated cause and effect relationships exist between air and water quality and land use. Therefore, air and water quality are considered as dependent variables responding to land use within the framework of the hydrologic cycle (Fig. 5).

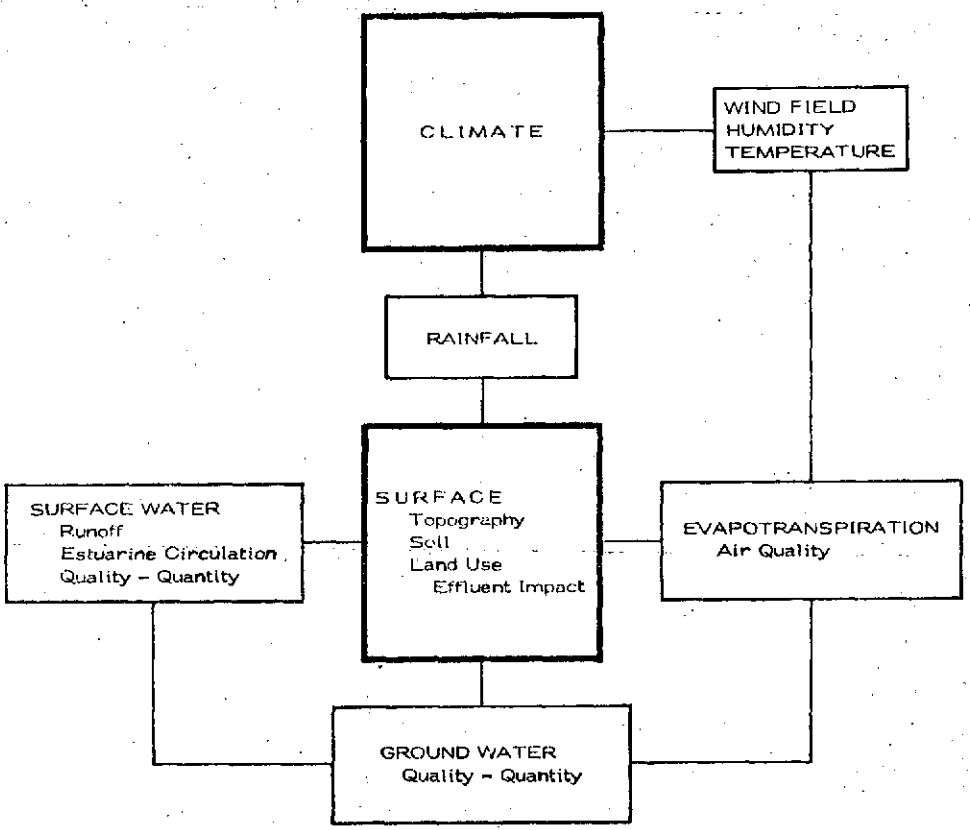


Fig. 5 RICHEL Model Components. Black boxes represent major data banks.

The surface of the earth acts as both boundary and membrane in the hydrologic cycle. Surface slope (topography), permeability (soil) and cover (vegetation) are critical to runoff, percolation, evapotranspiration and to material transport in the cycle. At the same time the use of the land by man adds effluents to surface and ground water, which are aggregated into drainage systems and reservoirs, and to the air as additives to evapotranspiration.

A primary requirement of such a model is the identification and quantification of the environmental impacts of the various activities associated with land use: food production and processing, transportation and communication, raw materials production and processing, manufacturing and commerce, and habitation and recreation. Identified environmental effects of these activities are principally from the following; 1) fossil fuel consumption in power production, transportation, and heating; 2) fertilizer and pesticide application; 3) animal and human wastes; 4) accelerated erosion from construction, land use change, and drainage basin alteration; 5) industrial and manufacturing effluents; 6) solid waste generation and disposal; and 7) altered patterns of surface runoff and diminished ground water reserves.

The analysis explored herein is comprised of four modules which are mutually supportive and linked by land use; 1) a climatological-air pollution module, 2) a surface land use environmental module, 3) a river basin-surface runoff-estuarine circulation module, and 4) a ground water module. Each of these modules requires both geometric and kinetic references which are mutually referable.

Geometric Reference

The arguments which support regularly shaped information blocks about the Earth's surface far outweigh those in favor of irregularly shaped parcels of land whose geometry is defined by ownership and use, political boundaries or natural terrain features. The mathematical manipulation of the former is much easier than the latter and reaggregation into alternative boundary sets (i.e. political or census tract) is greatly facilitated.

The UTM grid system is the obvious choice for land subdivision. However, the selection of cell size is debatable. If too small, a substantial amount of effort must go into coding; if too large the likelihood of multiple land use within a cell increases which makes coding more complex. In addition, the aggregation of large cells into political or natural units becomes geometrically awkward. A cell which is 0.25 km on a side (0.0625 km^2) seems a reasonable compromise. The cell contains 15.43 acres and is about 820 feet square. On a high altitude aerial photograph of a scale 1:120,000 each cell would be about 2 mm on a side. In RICHEL 283,422 such cells would have to be identified and coded. The land use cells may be aggregated into river basin and air shed super cells for input into the modules for surface runoff, ground water percolation and air circulation.

Kinetic Reference

Each of the modules has unique kinetic scales: air - hourly to daily; surface water - daily to weekly; ground water - weekly to quarterly; land use - one to ten years. The lower end of these scales is required in extreme event analysis, high air pollution probability, flooding, drought, and urban fringe development. The longer scale would be used in the analysis of planning land use strategy and alternatives and in resource allocation analysis.

The response of the air and surface water systems to a change in land use is rapid, allowing land use to become the forcing function. However, the data sets and data upgrading must be within the smallest kinematic scale required of each of the four modules.

Climatological - Air Pollution Module

The Chicago air pollution model (Roberts, et al, 1970) is a computerized multiple source atmospheric dispersion model which takes into account transitions in atmospheric stability and mixing layer height. The simulation uses both instantaneous release (puff) effluent and the steady state Gaussian-plume dispersion to integrate both urban area sources and point sources from industry and power plants. The model thus synthesizes temporal and spatial variations in pollution sources and meteorology and therefore air quality. The model has been adapted to RICHEL by altering its matrix parameters, and by identifying and indexing the point and area effluent sources associated with RICHEL land uses (Appendix I).

The air pollution model requires hourly meteorological data:

Temperature
Wind Speed
Wind Direction
Stability Class

These are available from the two first order NOAA weather stations in the area, Richmond and Norfolk, and from Langley AFB, NAS Norfolk and NAS Oceana.

Yearly and even seasonal climatological characteristics of RICHEL may be constructed from existing data (Appendix A). However, the other environmental requirements in RICHEL are more demanding and will require the development of climatological event data sets which give on a probabilistic basis the effects of a specific meteorological event on a short time scale (Gringorten, 1966). These event components would be 1) centered on the pressure trough which dominates the United States east of the

Applachians from Florida to New England, 2) originally developed about the climatological seasons (Table II), and 3) refined by analyzing smaller and smaller event phenomenon associated with the trough such as the following (Hayden, pers. comm.):

Regional Events

- Return Polar cell
- Bermuda High
- East Coast Ridge
- East Coast Trough

Local Events

- Secondary Hatteras cyclone
- Hurricane
- Cold Front passage
- Warm Front passage
- Thunderstorm
- Arizona Cyclone

Singularities

- January Thaw
- Shift of Subtropical Anticyclone
- March 27th (See Table II)

The events would be used to analyze the spatial development over RICHEL of such data sets as air pressure and humidity, precipitation, wind direction and velocity, and atmospheric stability. These are linked to land use which partitions the precipitation, loads runoff and insoak with effluents, affects evapotranpiration, and initiates air pollution.

Land Use - Environmental Impact Module

The principal land use data base for RICHEL is in the 1970 NASA Mission 144 high altitude photography (Appendix B), supplemented by other aerial photography(Appendix B), and from existing land use inventories (Appendix C). The USGS is preparing 1:250,000 scale photomosaics from the false color infrared photography of Mission 144 which will be available for coding. Each cell of .0625 km^2 requires these types of data:

Cell Data Requirements

Locational	Physical	Environmental
UTM grid	Slope	Erosion Index
Political Subdivision	Soil Type	Water Budget Parameters
Census Tract	Land Use	Land Use Impacts
Drainage Basin		Population Impacts
Aquifer Recharge		

Additional data could be coded at the same time which would be of great help in economic, social and political interactive studies: ownership, tax assessment, zoning, social indices, and condition (quality).

The locational data are required for the collation of physical and environmental data sets, for planning, and for the assignment of runoff and recharge. Map overlays are required for each set of the locational information. Any modern programable digitizer will reduce the overlays to the UTM grid at a common scale.

The physical data are required for the assignment of environmental impacts. The source of slope data are USGS topographic maps. Only the western most edge of RICHEL is not covered by USGS 7 1/2 minute quadrangles of scale 1:24,000 (Appendix D). Overlays are required for each of the counties and independent cities which give topography in the following categories: 0 - 2%, flat; 2 - 14%, sloping; and greater than 14%, steep.

General soil maps will be available by June, 1972 for all of the counties and independent cities. Those available now are given in Appendix D. Overlays of the soil maps must be drafted and geocoded. The hydrologic characteristics of a soil are a function of slope, vegetation (land use), and its physical characteristics and will be discussed later. For any given intensity of precipitation (climatological event) water is partitioned into runoff and insoak. Given soil moisture, climatological parameters and vegetation type (land use) evapotranspiration may be calculated. Evapotranspiration in the coastal plain is greatest in June and July reaching 0.16 inches per day (Van Bavel and Lillard, 1957). Land use coupled with climatological events, topography, and soil type generate the environmental impacts.

The land-use classification of the GAP is not sufficiently detailed to calculate anything but very general environmental impacts (Table III). One of its major shortcomings is the lack of provision for a "construction" category (including dredging, mining, building and earth moving), a major cause of erosion and siltation, under Level II. It is an area where remote sensing could play an important role in monitoring construction pollutants.

The Urban and Built Up category of the classification requires additional information in order to even begin to treat environmental impact.

The residential category should specify single or multiple family dwelling; industrial either heavy or light; transport routes either rail or highway. In addition the following data are required for each category: type and quantity of fossil fuel consumed, electrical power consumption, water supplied, waste production and treatment, paved areas and traffic densities are needed as area, line, or point data. These are most readily available from the appropriate state agency, political jurisdiction or from census data. These may vary greatly from county to county. The data for RICHEL are given in the appendices of this report and are discussed further in a later section of the text.

The lack of specificity in the classification is the next biggest shortcoming. All of the non-urban categories require a Level III breakdown in order either to assess the environmental impact of the use or to weigh the relative impacts, environmentally and economically, of alternative uses.

<u>Agricultural</u>: Acreages of specific crop types are required so as to assign water, pesticide and fertilizer seasonal loadings by quantity as well as to calculate the dollar value of the land. In addition, there are seasonal fallow, plowing, and rotational constraints peculiar to crop types which are important in the hydrologic cycle and to erosion (Ogrosky and Mockus, 1965). Feedlot operations must specify the type of animal being fed as well as animal density in order to estimate waste production, water requirements, and dollar value.

<u>Forestland</u>: As a minimum hardwood, pine, mixed, and swamp forest types are required both for calculations in the hydrologic cycle, in

ecosystem evaluations, for economic worth, and for the evaluation of the environmental impact of forest fires.

Water: The principal use of each of the Level II categories is required with emphasis on recreation, water supply or flood control, and commercial and power generation applications. Each of these has specific environmental impact and economic association which must be weighed.

Non-Forested Wetland: A distinction must at least be made between salt and fresh water wetlands. These have very different ecological productivities, ground water recharge characteristics, and potential economic worth.

Barren Land: No provision is made for dunes which are very delicate from an environmental point of view and are extremely valuable from a recreational aspect. A distinction between bare (shifting) and grass-covered (stabilized) is probably required for a complete environmental assessment.

Correlative Sources of Non-Urban Land Use Data:

The photographic data base of the land use inventory can be verified and supplemented using alternative inventory data sets. These are also of use in establishing rates of change. In RICHEL the fastest changes in land use are in urban growth with an almost 500% change recorded in Chesapeake County between 1958 and 1967 (Table IV). This growth has occurred chiefly at the expense of pasture land and secondarily at the expense of cropland (Table V). The percentage of forest land has remained essentially constant. An interesting corollary to increasing population is the steady increase in small water areas for recreation and water supply

(Table V). The forests are principally hardwood of oak and hickory, secondarily of loblolly pine, and last of mixed oak-pine (Table VI); an important distinction in computing evapotranspiration. The crop with uniformly high acreage in RICHEL is corn, exceeded in some counties by soybean and peanuts. Hay is the largest non-row crop (Table VII). Crop type is important in assigning erosion and fertilizer/pesticide algorithms.

The latest farm census for which data is currently complete was in 1964. The 1969 farm census data has not yet been released. Both the number of farms and the total acreage in farms decreased in every county but one in RICHEL between 1959 and 1964 (Table VIII). On the other hand every county shows an increase in the size of the average farm. Both of the independent cities of Virginia Beach and Chesapeake show slight increases in farm area in spite of increased urban area (Table IV and VI). Both cities had abnormally large decreases of pasture and forest (Table V).

Surface Water - Estuarine Circulation Module

A digital surface water runoff and stream flow model for the James River west of the fall line at Richmond should be adapted from existing models (Linsley and Crawford, 1966, Holten and Lopez, 1971; Chen and Chow, 1971; Claborn and Moore, 1970) as input into the estuarine circulation model. The 16 stream flow stations operated by the U.S. Geological Survey and 21 stations matintained by the Virginia Division of Water Resources in the James Basin (VDCED, 1970b), many of whose records go back more than 40 years provide an adequate data base for the model.

The average discharge for the James River at Richmond over the past 35 years is 7,127 cfs. Over the decade ending 1968 the highest average flow rates were recorded in February and March; the lowest in September with more than five times less discharge (Table IX). Only two major rivers enter the James estuary below Richmond: The Appomattox with an average discharge of 1,165 cfs. and the Chickahominy with 253 cfs. Both rivers record maximum and minimum flow rates in the same months as does the James at Richmond (Table X and XI). The most probably 1-day and 7-day low flows for the James River near Richmond have a 1.55 year recurrence; the mean 1- and 7-day low flow recurrence is 2.33 years (Fig. 7) as is given on the following page:

Most Probable and Mean Low Flow
Discharges from Frequency Curves (VDCED, 1970b)

	Area mi.^{2}	Days Low Flow	Most Probable cfs	Most Probable cfs/mi.^{2}	Mean cfs	Mean cfs/mi.^{2}
James near Richmond	6,757	1	1,350	.199	1,050	.156
		7	1,550	.230	1,260	.187
Appomattox near Petersburg	1,335	1	195	.146	107	.080
		7	225	.169	132	.099
Chickahominy near Providence Forge	249	1	21	.083	17	.068
		7	25	.099	20	.080

Flow duration curves represent that percent of the time specified flow rates are exceeded at given station. The James River near Richmond exceeds 5,000 cfs. 50% of the time (Fig. 7). The ratio of floods to the mean annual flood interval (2.33y) to flood recurrence is correlatable (Fig. 8) as is the size of the drainage area ot the discharge rate of the mean annual flood (Fig. 9). Two methods of analysis yielded similar results in relating flood recurrence interval to discharge (Fig. 10). Finally, there is reasonable correlation between drainage area and discharge for each flood frequency occurrence (Fig. 11). The relative success of these analyses is in large part a function of the integrative data period, and the probablistic approach to the analysis.

Discharge prediction based on either daily precipitation or meteorologic event precipitation has not been accomplished for the basin. Specific land use data would not be necessary for such a model; rather a soil cover complex parameter would be generated to estimate runoff. The output from that would input the estuarine circulation model.

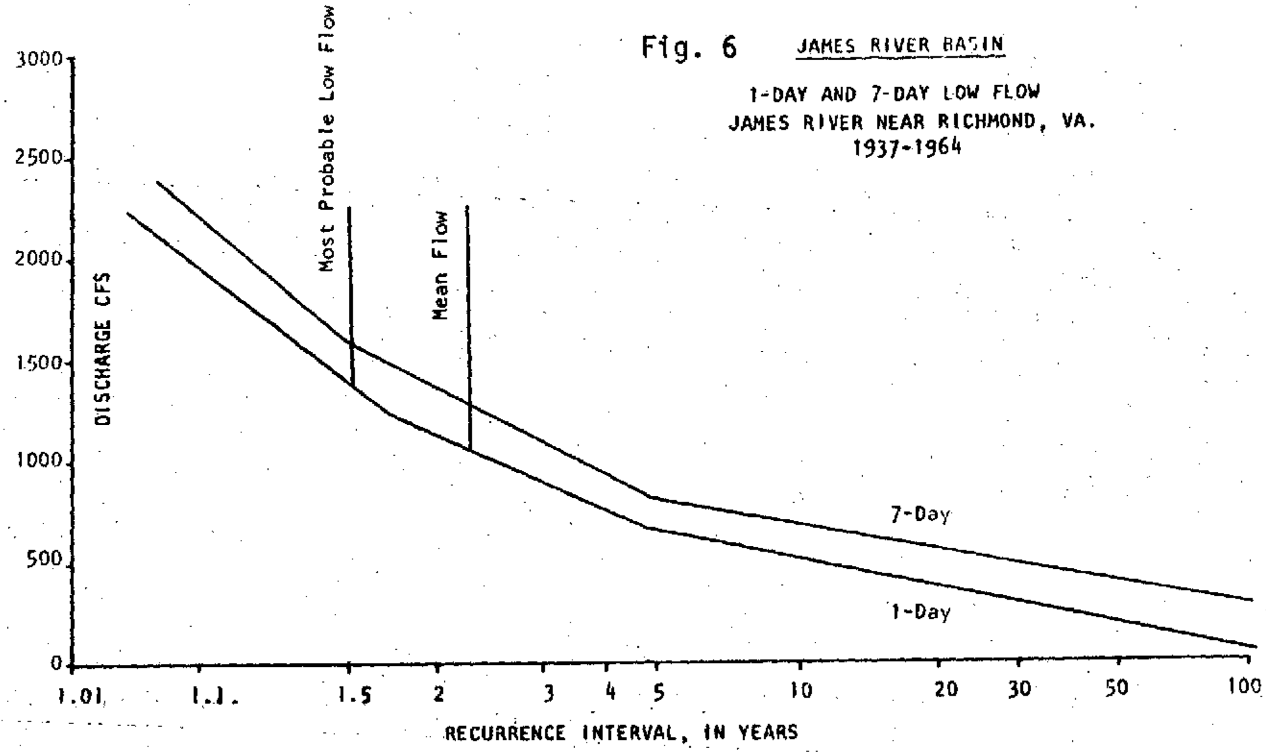


Fig. 6
JAMES RIVER BASIN
1-DAY AND 7-DAY LOW FLOW
JAMES RIVER NEAR RICHMOND, VA.
1937-1964
DISCHARGE CFS
Most Probable Low Flow
Mean Flow
7-Day
1-Day
3000
2500
2000
1500
1000
500
0
1.01
1.1
1.5
2
3
4
5
10
20
30
50
100
RECURRENCE INTERVAL, IN YEARS

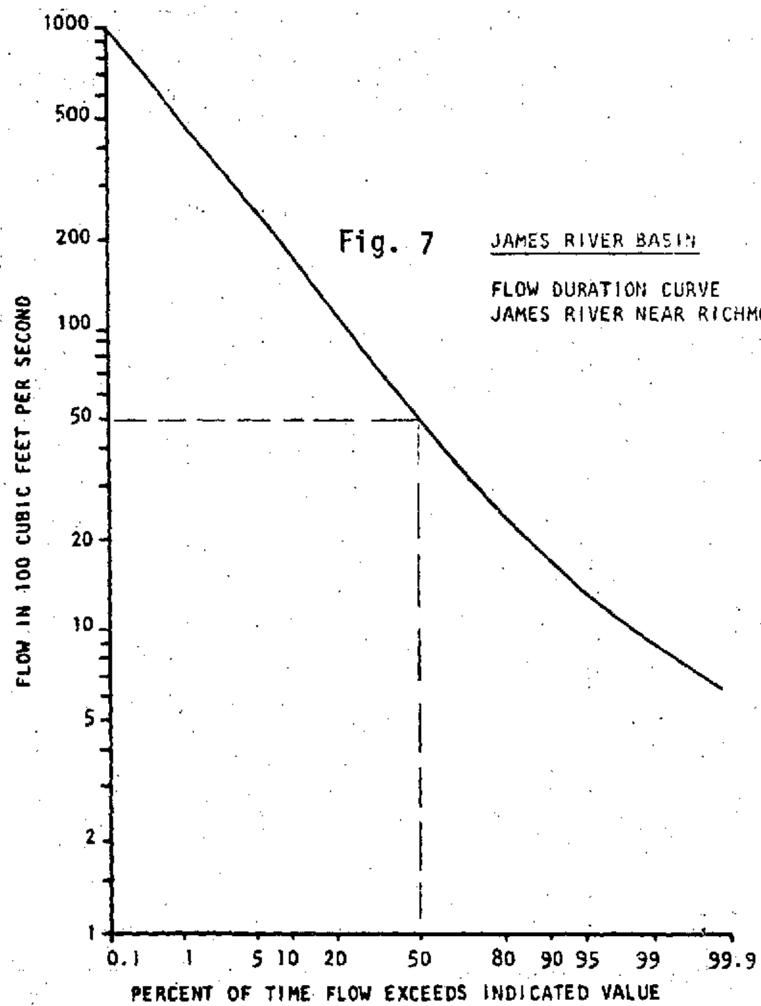
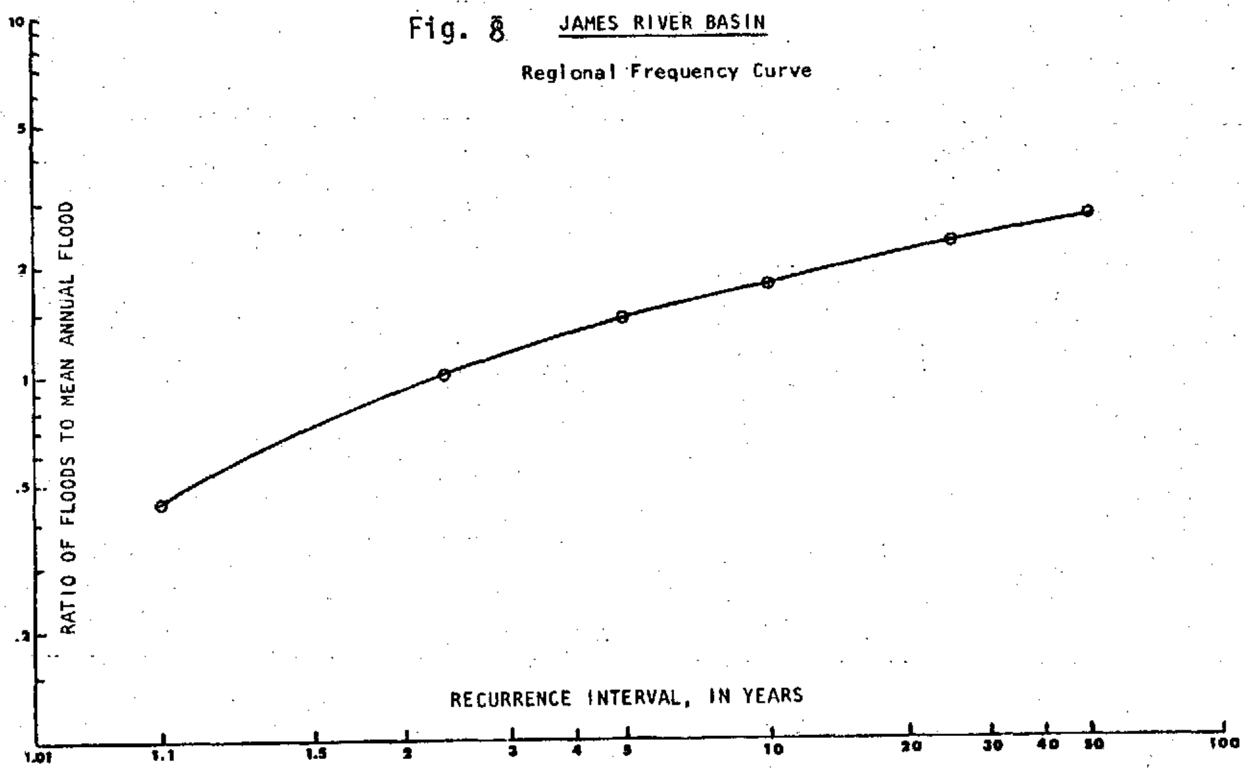
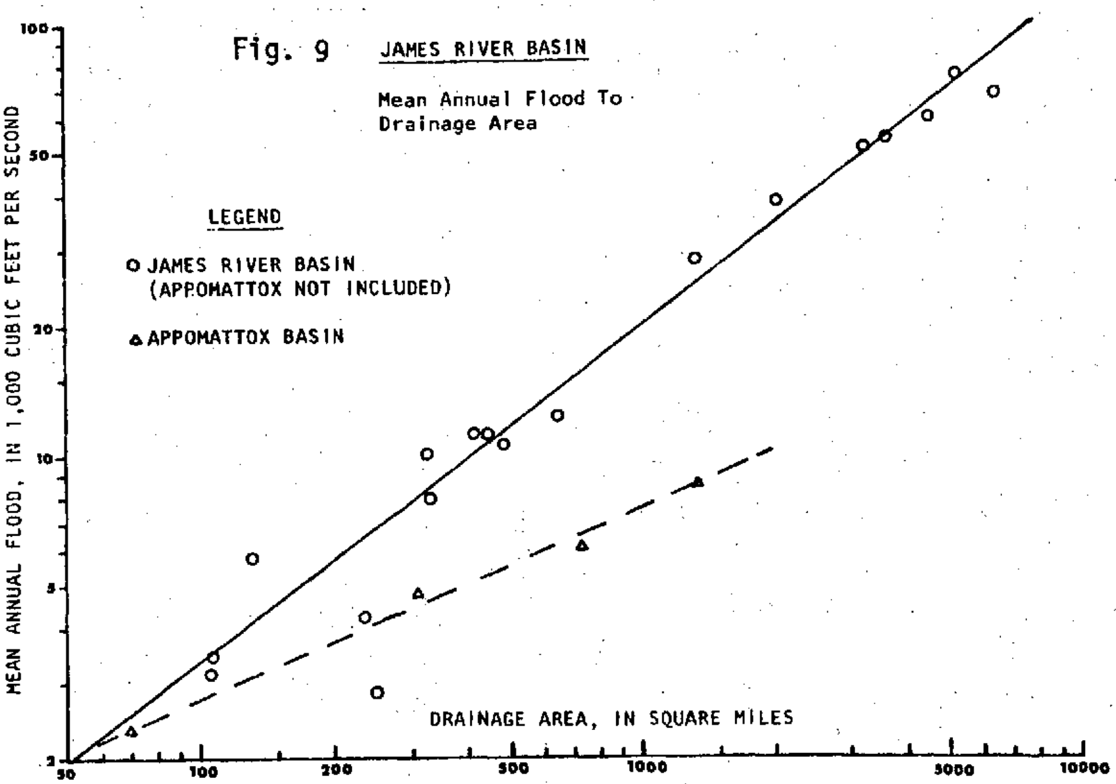


Fig. 7
JAMES RIVER BASIN
FLOW DURATION CURVE
JAMES RIVER NEAR RICHMOND, VA.
FLOW IN 100 CUBIC FEET PER SECOND
1000
500
200
100
50
20
10
5
2
1
0.1
1
5
10
20
50
80
90
95
99
99.9
PERCENT OF TIME FLOW EXCEEDS INDICATED VALUE





Source: VDCED, 1970

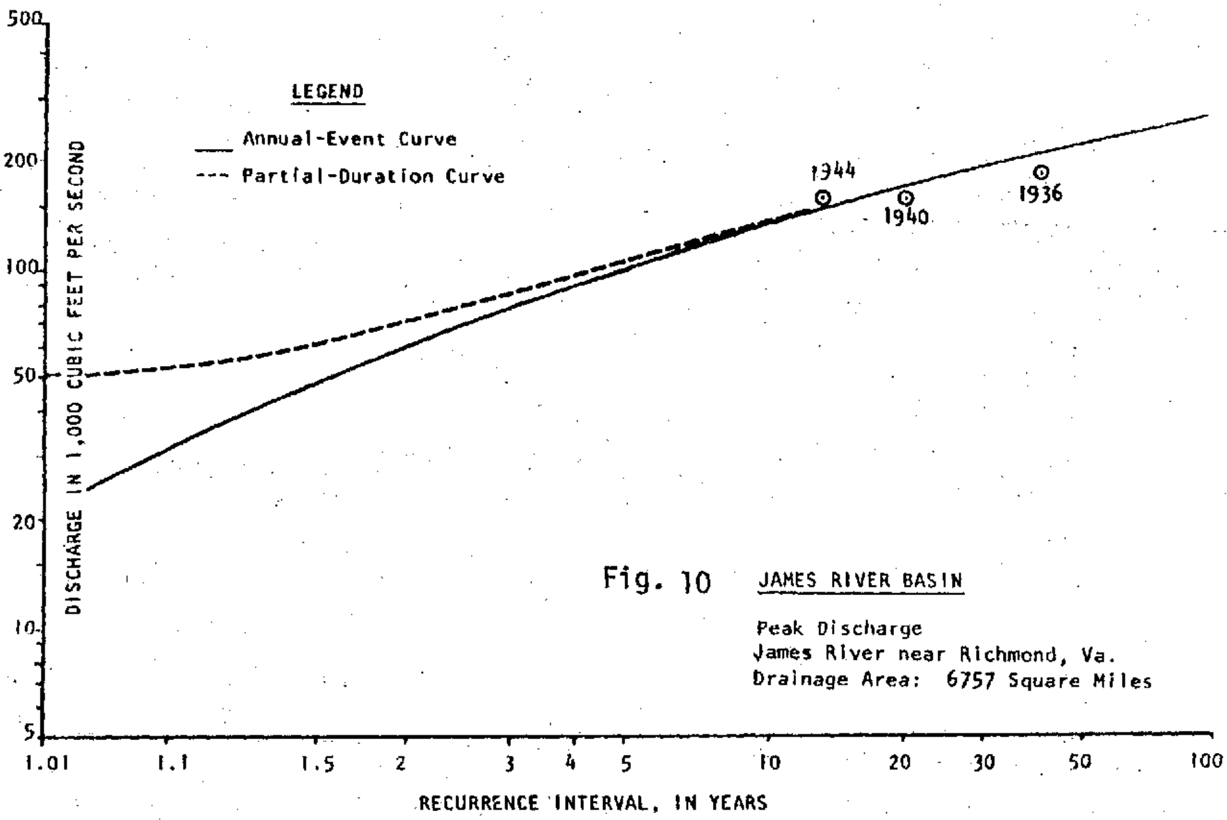


Fig. 10 JAMES RIVER BASIN

Peak Discharge
James River near Richmond, Va.
Drainage Area: 6757 Square Miles

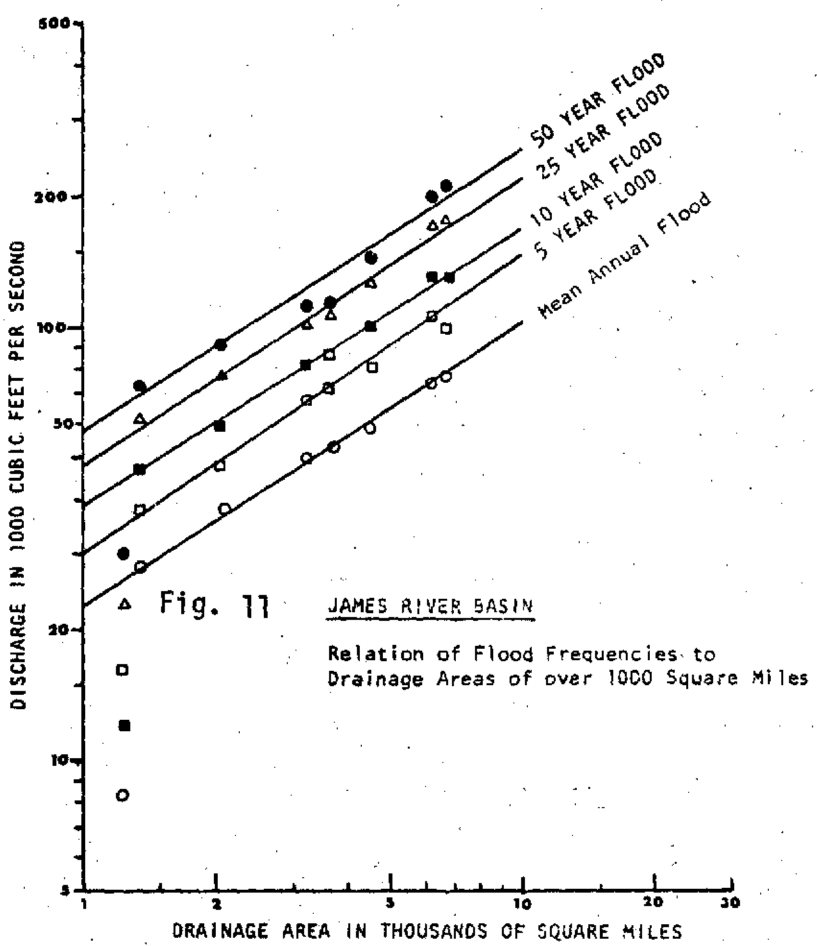


Fig. 11 JAMES RIVER BASIN

Relation of Flood Frequencies to
Drainage Areas of over 1000 Square Miles

Source: VDCED, 1970

The circulation model was developed in order to trace a pollutant from an estuary headwaters to its mouth, a situation which exists in the James Estuary.

Mathematical Development

The model is capable of predicting a pollutant concentration and distribution in a two dimensional field based on a given velocity distribution. Mathematically it utilizes a difference scheme based on an absolutely conserving form for the convective elements of the scheme. As such the conservation is algebraic and independent of the accuracy of the solution. This is necessary in that convection terms written in standard flux form are conservative for quadratic quantities but in the case of discrete convection conservation of quadratic quantities are not absolutely conserved. As shown by Piacsek and Williams (1970), the flux form is not adequate for prediction unless the process involved has the continuity variable $D = \nabla \cdot \overline{V} \equiv 0$. The presence of a non-zero D can lead to serious problems of stability in computations involving small diffusive terms.

It has been shown (Piascek and Williams, 1970; Roberts and Weiss, 1966) that in cases involving the forced convection of a scalar by a prescribed velocity field that the equation becomes a linear, variable coefficient, partial differential equation for T.

$$\frac{\partial T}{\partial t} = - \overline{U}(x,y) \cdot \frac{\partial T}{\partial x} - \overline{V}(x,y) \cdot \frac{\partial T}{\partial y}$$

where, T = the advected scalar and the bar implies that the velocity is held constant over the period of time integration.

For the convective equation we define the following central difference operators:

$$\frac{\partial T}{\partial t} = - \bar{u}(x,y) \cdot \frac{\partial T}{\partial x} - \bar{v}(x,y) \cdot \frac{\partial T}{\partial y}$$

$$\delta_x T \equiv \frac{1}{\Delta x} [T_{x+\frac{\Delta x}{2}} - T_{x-\frac{\Delta x}{2}}]$$

$$\bar{T}^x \equiv \frac{1}{2} [T_{x+\frac{\Delta x}{2}} + T_{x-\frac{\Delta x}{2}}]$$

and

$$C_3(\bar{u},T) = \frac{1}{2\Delta x} [U_{x+\frac{\Delta x}{2}} T_{x+\Delta x} - U_{x-\frac{\Delta x}{2}} T_{x-\Delta x}]$$

Thus the advective equation becomes

$$\frac{\partial T}{\partial t} = -C_3(\bar{u},T) - C_3(\bar{v},T)$$

With the addition of the diffusive terms the final finite difference equation has the form:

$$\frac{1}{2\Delta t} (T^{\tau+1}_{i,j} - T^{\tau-1}_{i,j}) = -C_3(\bar{u},T^{\tau}) - C_3(\bar{v},T^{\tau})$$
$$+\mu_x [T^{\tau-1}_{i+1,j} + T^{\tau-1}_{i-1,j} - 2T^{\tau-1}_{i,j}]$$
$$+\mu_y [T^{\tau-1}_{i,j+1} + T^{\tau-1}_{i,j-1} - 2T^{\tau-1}_{i,j}]$$

where μ_x and μ_y are the diffusion coefficients for the x and y components, respectively. This form utilizes the "leap frog" method of solution and has a time truncation error of $O(\Delta t^2)$.

Necessary Inputs

The only requirements for useage of the quality model are the specifiction of the velocity field and the initial distribution of the pollutant concentration. It is necessary that the model utilize a regular grid, preferrably a square grid. For cases in which the physical geometry is irregular it would be necessary to carry out a coordinate transform so that the program loading routine would require the addition of a conversion routine to handle the transform.

Model Segmentation - Application of this model for environmental simulation is best accomplished by dividing the estuary first into broad sections then into individual segments.

The sections are based on the type of flow regime encountered.

Section 1 = riverine environment

Section 2 = estuarine environment

Sectioning is used primarily so that the amount of diffusion incorporated can be varied according to empirical evidence. As an example, it would be reasonable to assume, in rivers where there exists a reasonably large topographical gradient, that advection would dominate. As such, the diffusion coefficients can be loaded independently based on field observed data. Segmentation is used to further subdivide each section in order to improve spatial resolution and maintain regular geometry.

Velocity Field Input - The velocity field for a given segment can be loaded in two different manners.

1. Approximation of the two dimensional field by mathematical functions or,

2. specification of the u and v components at each grid point from observed data.

In application a steady-state system could be run in which the average flows for the entire river, estuary system would be specified for each segment. Quasi - time dependent cases would be run by updating the velocity field from segment to segment or within segments at discrete time intervals.

Comparison With Other Models - The proposed model is two-dimensional and represents horizontal advection and diffusion of a pollution by an Eulerian field description such that, at a given time, t_i, it is possible to know both the spatial distribution and the time rate of change of the distribution during the interval $(t_i - t_{i+1})$.

Crim (1970) presented a one-dimensional distribution along a well mixed channel. The channel approach is a good approximation to river flow except where rivers converge. Mixing must occur at the junction. In a two-dimensional model proposed by Fischer (1970) the riverine flow is assumed one-dimensional and estuarine flow two-dimensional. Again the technique of channel junction is employed. Fischer (1970), however, obtains instantaneous velocity values from the hydrodynamic program rather than averaged velocities. However, the trajectory of a pollutant marker particle is followed.

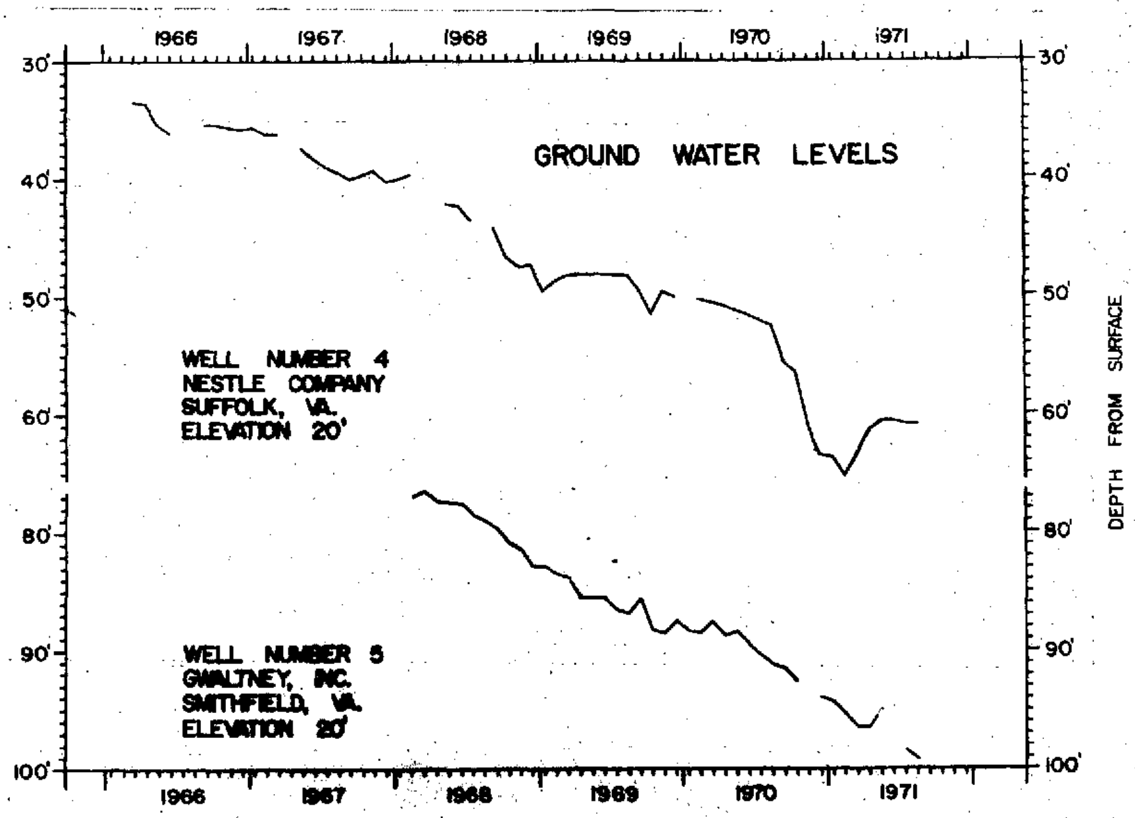
The distinct advantage of the two-dimensional Eulerian model is that the time rate of change of the concentration can be viewed at all grid points for all times. The model uses a real velocity field and does not have to rely on output from a hydrodynamical model. Further discussion of the computor components are given in Appendix K.

Ground Water Module

The quality and quantity of potable water is of growing national concern; in parts of RICHEL water will be rationed within this generation if better water management is not forthcoming. Water quality and quantity can be made a function of land-use and may be made part of any environmental model by using the proper hydrologic algorithms.

While surface impoundments are now the major water source of the large urban centers in RICHEL, ground water continues to serve the smaller cities and the rural population (Table XII). Wells drilled into the coastal plain sediments in southeastern Virginia prior to WWII flowed at the surface (Cederstrom, 1945). However, there has been an accelerated lowering in the piezometric surface which has dropped more than 20 feet in the last five years (Fig. 12). In addition, salt water is encroaching in some aquifers as fresh water is withdrawn (DeBuchananne, 1968). The existing ground water resources are probably adequate in the eastern part of RICHEL if properly conserved (Fig. 13). The quality of the water is generally good and even in those rare instances where analyses exceed the standards prescribed by the U.S. Public Health Service the water is amenable to treatment (Table XIII).

The aquifer beneath the James River Basin west of RICHEL ranges widely in lithology and is capable of only modest ground water yields. The western third of the basin is underlain principally by Paleozoic sediments and metamorphic rocks of the Appalachians; the central third principally by Lower Paleozoic and Pre-Cambrian igneous and metamorphic rocks of the Piedmont, intruded by Triassic sills and dikes and overlain



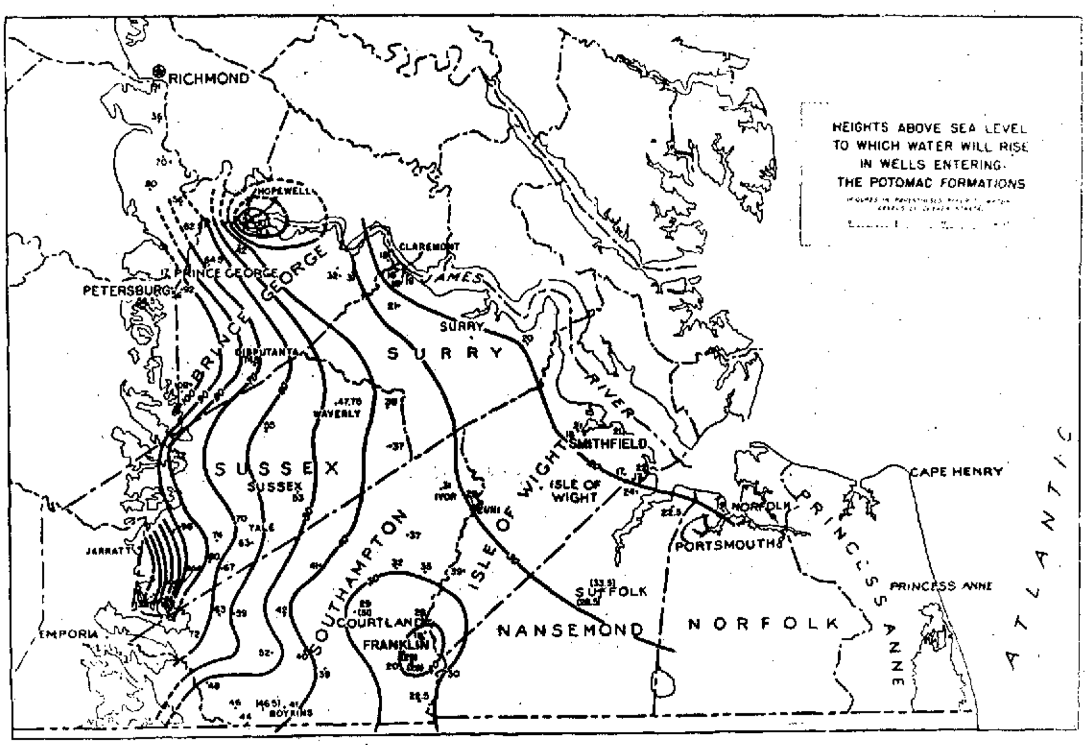


Fig. 12 Pieziometric surface in Suffolk and Smithfield, 1966-1971 (above), compared to pieziometric surface 1937-1939 (below).

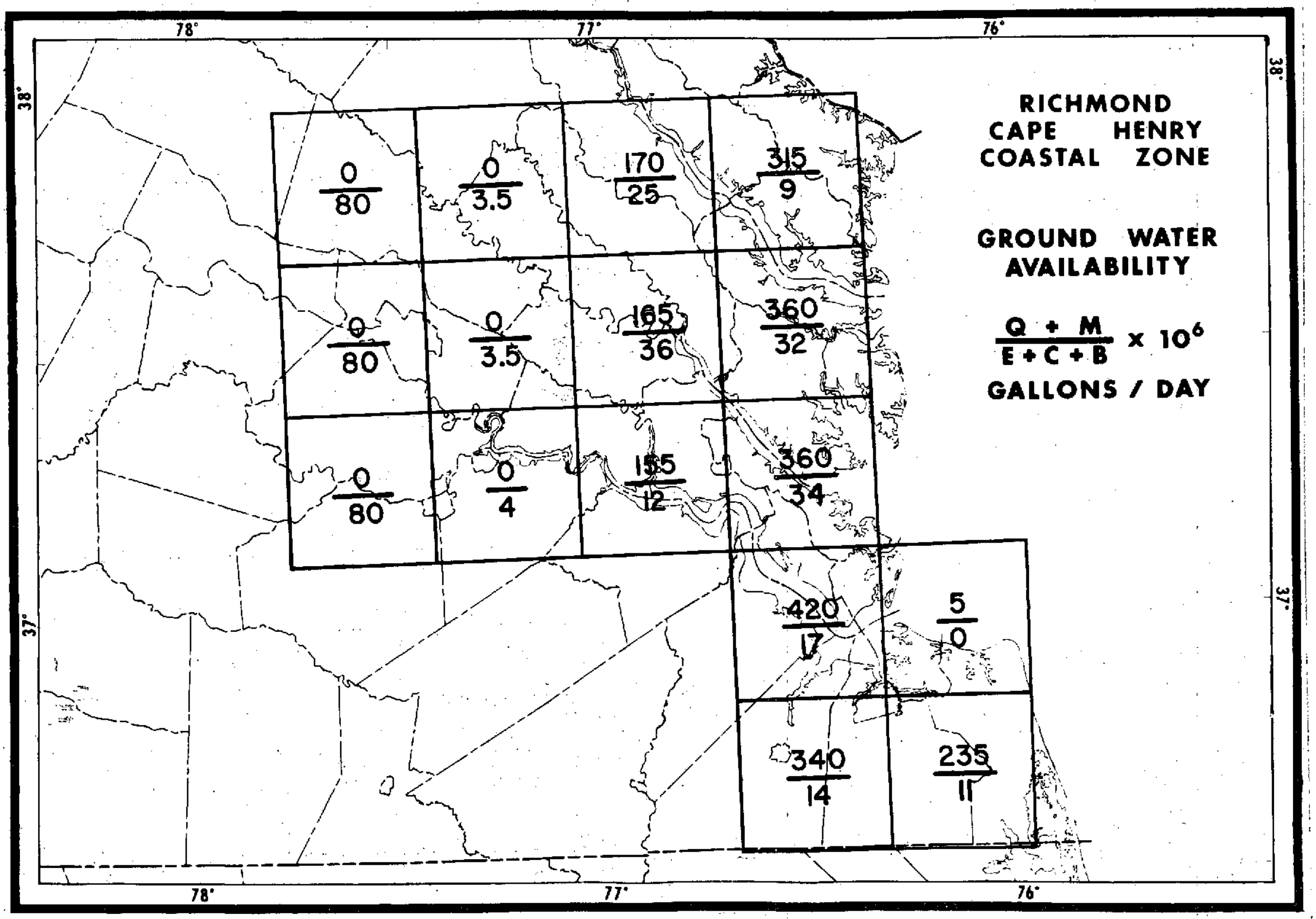


Fig. 13 Ground water availability by 400 sq.mi. areas: Q = Quaternary; M = Miocene; E = Eocene; C = Cretaceous; B = Basement in 10^6 gal/day (after DeBuchananne, 1968).

Triassic sediments of the Newark Group; the eastern third, corresponding roughly to RICHEL, by Cretaceous and younger sediments of the coastal plain (pocket rear cover). The transition from crystallines of the basin center to the eastern sediments is marked by the fall line, western limit of navigation. The outcrop (and recharge) of Cretaceous and Eocene rocks occurs here where they have not been overlapped by Miocene rocks of the Chesapeake Group and in the river valleys where they have been exposed by erosion. The basement crystallines are about 3,000 feet below sea level at Cape Henry. The wedge of Cretaceous and Tertiary sediments above the basement between the fall line and the coast constitutes the principal RICHEL aquifer (Table XIV). The chief water bearing formations in the western third of RICHEL are Cretaceous and Eocene rocks; over the remainder of the area the chief ground water formations are in the Chesapeake Group which are subject to salt water encroachment from the estuaries when pumping is heavy. In the east Quaternary terrace deposits are second in importance; Eocene and Cretaceous rocks are third. The Miocene and Quaternary rocks outcrop over wide areas in RICHEL so that recharge is rapid. However, that also makes contamination from pollutants easier and interference from injudicious land use more probable.

A ground water management system is possible within RICHEL inasmuch as the entire aquifer including surface recharge outcrops lie within the area. A deterministic model for the prediction of water quality and quantity is feasible using existing models as point of departure. (Pinder and Bredehoeft, 1968; Pinder, 1970; and Pinder, et al, 1970). In these models the transmissivity of the surface (a function of land use) is a major hydrologic parameter. There is a sufficient well-monitoring network

(Appendix E) that given the proposed climatological and land use model a ground water model will logically follow.

ENVIRONMENTAL IMPACTS OF LAND USE

There are obvious environmental effects of man's presence in the world which go back to antiquity: deforestation and species extinction. However, not until the last two centuries when the medical revolution greatly decreased death rates resulting in exploding populations, and the industrial revolution radically increased the consumption of raw materials, has the existence of man on the earth become threatened by the impacts of his environmental degradation.

The greatest of these impacts revolve around man's activities in food production and processing, transportation and communication, raw materials production and processing, manufacturing and commerce, and habitation and recreation. These require 1) power still largely supplied by the burning of fossil fuels; 2) the application of nutrients and pesticides to fields; 3) the production of human and animal wastes in highly concentrated amounts; 4) the accelerated erosion from agriculture, construction and drainage basin alteration; 5) the generation of effluents by industrial and manufacturing and their discharge into the air and water; 6) the production of solid wastes in the production and processing of raw materials, in manufacturing, in construction, and in subsistence; and 7) interference in the hydrologic cycle by paving, damming, ditching, building, and dredging.

The identification and categorizing of the impacts is comparatively easy. The quantitative assessment of the effects of the impacts is extremely difficult. The data base at any but the national level is extremely sketchy. For example, the national per capita consumption of power, raw materials, food and water, and the per capita production of air, water, and solid waste effluents are readily available. These are useful in calculating mass balances for the assessment of the degradation dynamics of the global environment. However, they are of little use for the analysis of regional or local environmental impacts which are unique because of unique physical and population parameters. Using national per capita statistics would result in a uniform environmental impact which would vary only as population density. This is not the case. While population density is an extremely important factor in assessing impact, other activities which support that population, its economy and its culture, vary widely.

RICHEL Population Densities & Trends

The population of Virginia increased by 113% between 1900 and 1930 as compared to a 135% growth for the Nation as a whole. However, the rate of growth of the Commonwealth has exceeded the national rate since 1930:

Rate of Population Growth

Decade Ending	Virginia	U.S.
1940	10.6	7.2
1950	23.9	14.5
1960	19.2	18.5
1970	17.2	13.3

Like the Nation the greatest increases in population in Virginia have been in her urban areas (Sindwani, 1969; Howard, et al, 1970). In RICHEL for the decade ending 1970 the largest growth rates were either in the smaller cities or on the urban fringe of the major metropolitan centers (Appendix G). The highest rate in an urban area was recorded in Virginia Beach City, 7.3% per annum; in an urban fringe county, Chesterfield (Richmond & Colonial Heights) 5.8%. The largest sustained growth in population through 2020 is predicted in planning district 15, which includes the city of Richmond, and 21 which includes the cities of Newport News and Hampton (Appendix G). In planning districts 19 and 20, 9 counties and cities experienced a net loss in population during the decade and are projected to continue to decline through 2020. Provisional estimates of population change between 1970 and 1971 reveal growth rates somewhat below the 1960-70 annual rates. The data show largest losses occuring in the major metropolitan areas with a corresponding continued rapid build-up in the urban fringe counties (Appendix G).

Howard, et al, 1970, found the population of the counties comprising Virginia's urban corridor to be younger, more highly educated, more concentrated, more mobile, better housed, paying more for their housing and having higher incomes than the population of the "buffer" counties to either side.

Housing in the predominantly urban or urban-fringe counties in RICHEL follows distinctive patterns (Table XV): 1) the percentage of multiple housing units is higher, 2) the structures are newer (% with plumbing), 3) have more congestion (persons/room), and 4) are at higher cost. There are additional obvious differences in population density (Table 1, Appendix G). The highest housing densities outside of the urban areas are in the counties of the urban fringe, especially in planning district 21 on the York Peninsula (Table XVI). In the cities of Norfolk, Portsmouth, and Petersburg, housing has remained essentially static over the decade while the city of Suffolk and Greensville county have had dramatic housing losses.

Population densities, projection, and housing characteristics should be assigned from census tract overlays and reduced to the UTM master grid. Environmental data which can be assigned on a per capita basis such as effluent production and power consumption can now readily be keyed to population (Appendix G,I,J).

Hydrology and Erosion

Man locally affects the hydrologic cycle by 1) increasing runoff through agriculture and construction, 2) changing patterns of evapotranspiration, 3) adding particulates from burning which act as condensation nuclei, 4) causing changes in soil moisture and the water table, and 5) creating heat sources from urban areas.

Jens and McPherson (1964) list the following specific effects which result from urbanization and stress that many of these are so interrelated that assignment of relative importance to them is not practical:

1. Increase in both total water use and per capita use.
2. Increasing development of new water-supply sources that may require transportation over great distances.
3. Increasingly frequent conflicts wherein two or more types of water users seek the same supply.
4. Diminished streamflow as a result of diversions of water.
5. Declining water levels and pressure in ground water reservoirs. (Also causing pollution of groundwater by leakage from sanitary sewers.)
6. Increasing number of artificial recharge projects, for purposes of water supply and flood control.
7. Increase in amount of wastes disposed to streams and possible increase in pollution when wastes are inadequately treated.
8. Increased re-use of waste water in agriculture and industry.
9. Land subsidence.

One method of estimating runoff is by the rational formula:

$$Q = CIA$$

where Q is peak discharge in cfs, C is a runoff coefficient dependent on surface characteristics, I is rainfall in inches per hour, and A is drainage area in acres. The runoff coefficient is as high as 0.95

in urban areas and from 0.10 in woodlands to 0.50 in heavy clayey soils of low permeability (Appendix H). Pavement therefore increases runoff from two to almost ten times. Urban areas are from 50 to 80% paved or roofed. There are a minimum of 43,571 acres of paving in RICHEL (Table XVII), an estimated 25,185 acres of residential roof tops and an unknown amount of access roads, parking lots, sidewalks, and industrial and commercial roofing. The implication for urban hydrology is obvious. Jens and McPherson (1964) have categorized other effects of urbanization as hydrology (Table XIX). Along with increased runoff goes increased erosion. Overlays of slope and runoff coefficients, keyed to the locational grid, will establish runoff discharge for any climatolotical event.

Losses caused by erosion in the James River Basin amount to an estimated $\$5.7 \times 10^6$ annually (VDCED, 1971). Most of this loss is due to the intervention of man with the Earth's surface. Erosion in a forested primitive area in the eastern United States is typically about 10 tons of sediment per square mile per year (Wolman, 1971). Cultivation raises that yield from about 100 to 1,000 tons and construction from 100 to 100,000 tons! In contrast sediment yield from urban areas is about 50 tons per square mile per year with an increase in surface runoff of about three times (Wolman, 1971). The U.S. Department of Agriculture soil conservation service accepts soil loss tolerance of from one to five tons per acre per year of cropland (640 to 3,200 tons $mi^{-2}y^{-1}$) depending on soil type and has developed a soil loss predicting equation which permits soil management options:

$$A = K R L S C P$$

where, A is the average annual predicted soil loss in tons per acre per year
K is the soil erodibility factor
R is the rainfall factor
L is the length of slope factor
S is the percent of slope factor
C is the cropping management factor
P is the erosion control practice factor

All of the data required are available for RICHEL (Appendix H). As of 1967, 58.7% of the 806,656 acres of cropland and 65.4% of the 137,421 acres of pasture in RICHEL required some conservation practice (Appendix C).

Estimates of soil loss in the coastal plain by the U.S.D.A. in tons per acre per year are as follows: cropland, 3.83; cropland treated for soil conservation, 1.92; pasture, 0.85; forest, .28; urban, 5.78; other, 11.2 (VDCED, 1971). These coefficients applied to the land use inventories in Tables IV and V generate more than 8×10^6 tons of soil lost from RICHEL annually, 37.1% of which is generated from urban areas (Table XIX).

There are 548,511 residential housing units in RICHEL. Of these 108,759 were added in the decade ending 1970 (Table XVI). To meet the transportation needs of the 283,874 additional people in these houses (Table 1) 495.45 miles of urban streets were added between 1965 and 1970 alone as well as additional arterial and interstate roads (Table XX). Assuming that all of the acreage for the urban fringe growth occurred at the expense of pasture (Tables IV and V), then about 100×10^6 tons of soil were eroded during house construction on 125,900 acres (1958 to 1967, Table IV). A like amount is estimated to have been lost during road and highway construction during the same period.

Although these sediments eventually end up in RICHEL drainage systems, there are no data more recent than 1956 on the sediment loads of the James River (Appendix H) that loading appeared to almost double between 1951 and 1955. The Virginia Department of Conservation and Economic Development estimates that approximately 76,200 tons of sediment are deposited in the 25,390 acres of marsh and tidal creek which border the James estuary below Richmond. The imagery taken by NASA in 1969 and 1970 clearly shows the degree of water turbidity in these marginal tidal creeks and marshes as in the estuary east to Cape Henry. Since 1951 the Corps of Engineers have removed an average of 1,266,000 cu.yds./yr. of spoil from the river and estuary as follows:

James River Dredging for Channel Maintenance
for 5 Year Periods Ending the Year Shown
(1,000 cubic yards)

	1955	1960	1965	1970	Total
Richmond Harbor	204	179	195	188	766
Richmond DWT[1]	676	592	552	699	2,519
RDWT[1]-Hopewell	677	639	611	856	2,783
Jordan-Harrison Bar	848	808	2,044	2,414	6,114
Dancing Pt.-Swann Pt.	0	3,106	1,755	1,826	6,687
Goose Hill Channel	738	1,994	880	744	4,356
Tribal Shoal Channel	392	1,266	309	138	2,105
Total	3,535	8,584	6,346	6,865	25,330
Cubic yds/yr	707	1,717	1,269	1,373	1,266

[1]Richmond Deep Water Terminal

Source: U.S. Army Corps of Engineers, Norfolk District

It is inevitable that some of the sediment spoil displaced by dredging ends up in the tidal creeks and marshes adjacent to the estuary adding to their already great siltation problems. Even disposition of the dredge spoils presents an impact to overstressed estuarine shore environments. Both problems will become acute if the channel is deepened to 35 ft.

The soil and slope overlays, together with the erosion factors, will permit prediction of erosion loss and siltation routing. A change in land use will alter these factors and therefore erosion and siltation. If the model is operationalized, the suspended load of drainage system in RICHEL could be used for verification. This could be monitored by remote sensing and quantified by sampling.

Power Consumption

One of the major impacts of man on the environment stems from the production of power. In 1968 the per capita consumption of energy in the U.S. was 312×10^6 BTU; the vast majority of which is generated by the combusion of fossil fuels (Fig. 14).

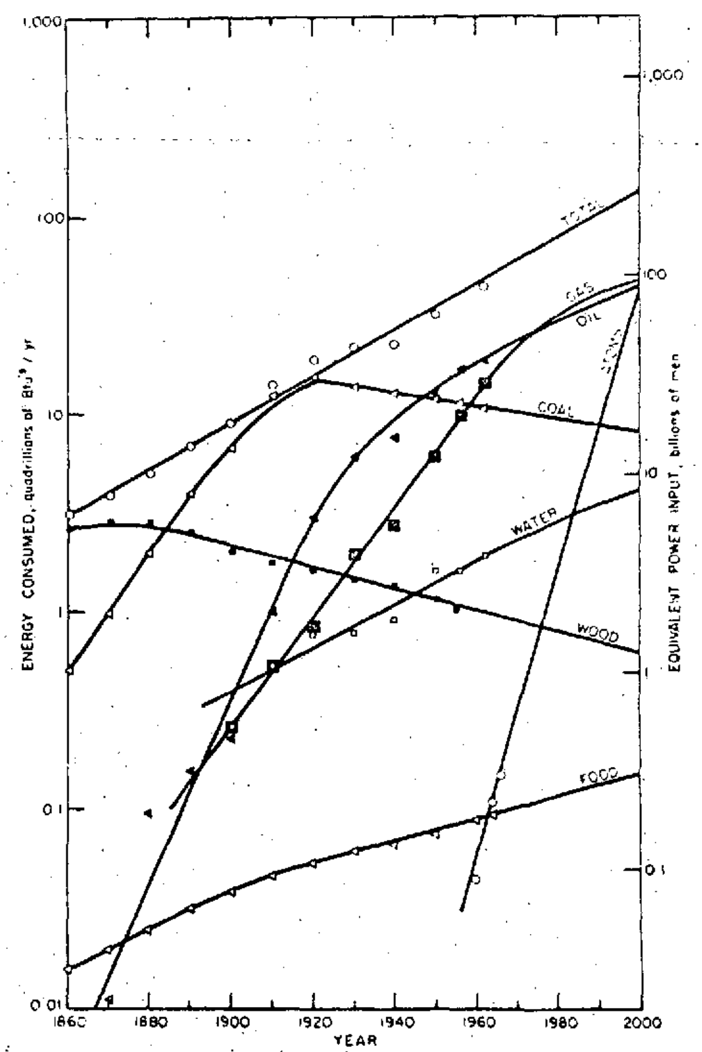


Fig. 14 Energy consumed in the United States by source, years 1860-2000. (Larsen, 1967)

This production is distributed among the following activities:

National Energy Consumption By Activity

Activity	Gross Annual Consumption 1968 (10^{12} BTU)
Transportation	15,135
Electricity Generation	14,945
Indistrial	14,348
Household and Commercial	13,600
Miscellaneous	296
Total	62,424

The production of power creates 1)solid waste from strip mining, 2) heat from combustion and electricity generation, and 3) air and water pollutants from fuel processing and combustion. Of these, air pollution has the greatest impact. The potential for high air pollution in RICHEL has existed about 30 times between 1960 and 1969 (Fig. 15). Transportation produces about 60% of the air effluents, almost twice as much as industry and utilities combined as is given below:

Sources of Pollutants Emitted Into United States Air in 1966

Source	Total	Carbon Monoxide	Hydro-carbons	Nitrogen Oxides	Sulfur Oxides	Particulates	Miscellaneous
			Emissions, millions of tons/year				
Transportation	74.8	59.6	9.7	3.1	0.5	1.8	0.1
Industry	23.4	1.8	3.7	1.6	8.7	6.0	1.6
Electricity generation	15.7	0.5	0.1	2.4	10.2	2.4	0.1
Space heating	7.8	1.8	0.5	0.8	3.4	1.2	0.1
Refuse disposal	3.3	1.3	1.0	0.1	0.2	0.6	0.1
Total	125.0	65.0	15.0	8.0	23.0	12.0	2.0
			Emissions, % of total				
Transportation	60	91	65	39	2	15	5
Industry	18	3	25	20	38	50	80
Electricity generation	13	1	1	30	44	20	5
Space heating	6	3	3	10	15	10	5
Refuse disposal	3	2	6	1	1	5	5

Source: Larsen,1967

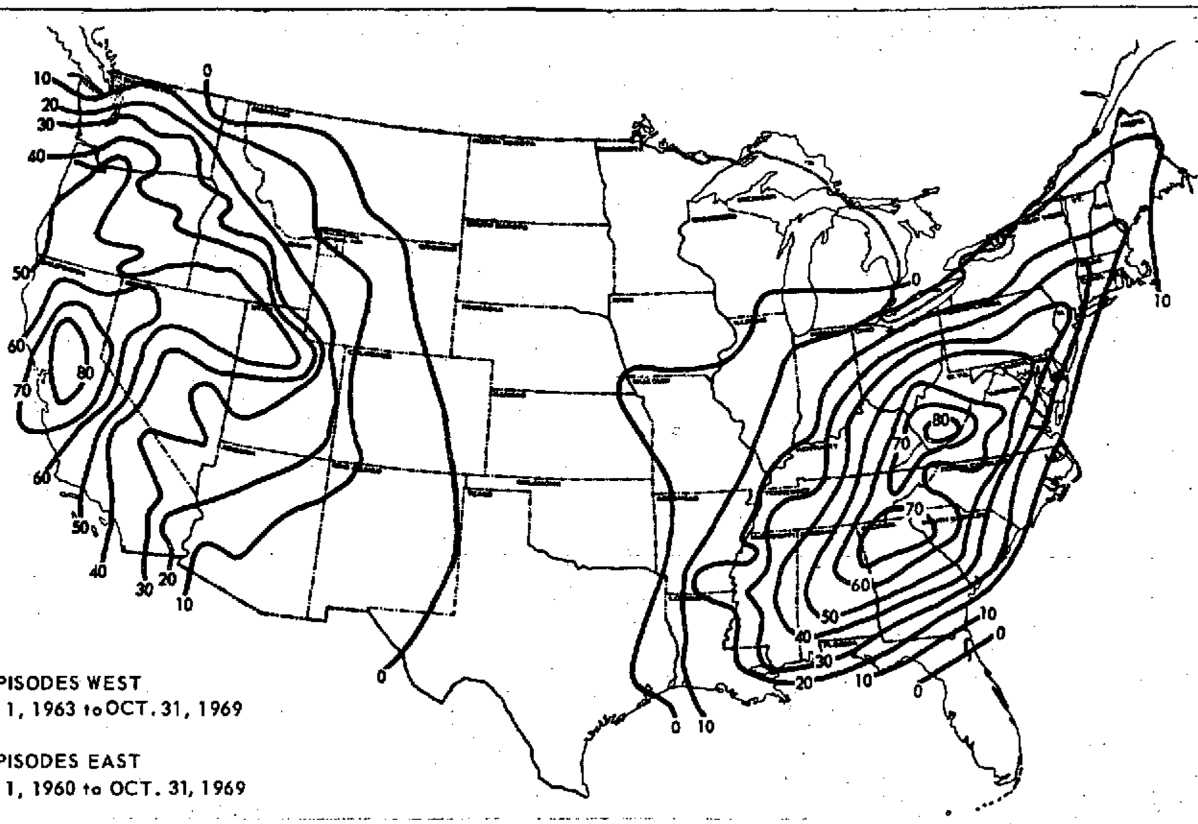


Fig. 15. Forecast high air pollution days (after EPA AP-76).

Transportation

There are 784,537 vehicles registered in RICHEL in 1971, more than an 11% gain in two years (Table XXI). Vehicles are being added at more than four times the rate the population is growing! The number of people per vehicle ranges from a low of 1.61 in Suffolk City to a high of 5.88 in Franklin City with an average for RICHEL of 2.31 in 1971. However, only estimates exist of the rate of combustion of fuel by these vehicles. Only one major oil company of several contacted was able to compute the gallons of its fuel pumped by county (the data was also available by zip code). This sample was not considered adequate for analysis.

The Commonwealth of Virginia receives only state-wide monthly sales reports from fuel distributors. The taxes from these are redistributed to the counties on a per capita basis. There were 2,445,341,855 gallons of automotive fuel sold in 1970 in Virginia; 526.2 gallons per citizen (Table XXII).

Fuel may also be allocated by vehicle miles traveled per stretch of road. Average daily vehicle densities by road and county are available from the Highway Department (pocket back cover). The Virginia Air Pollution Control Board uses 12 miles per gallon to calculate pollutant loading. However, a figure of 14 miles per gallon was used in Table XXII to compare fuel; a discrepancy of more than 36×10^6 (15.9%) gallons occurs between the methods. The 15.9% discrepancy closely matches the percentage of out-of-state passenger cars traveling the interstate and primary road systems as estimated by the Virginia Highway Department as follows:

Travel by Vehicle Type

Vehicle Type	% of Total Travel
Virginia Passenger Cars	61.28
Out-of-State Passenger Cars	18.06
Single Unit Trucks	14.00
Trailer Trucks and Buses	6.66
Total All Vehicles	100.00

Unfortunately, vehicle densities are only available as 24 hour averages from sporadic samplings. An urgent requirement for the RICHEL model are seasonal hourly samplings for 24 hour periods, weekdays and weekends. The assignment of vehicle generated pollutants was to calculate the 24 hour average of interstate, primary, and secondary vehicle miles traveled

(Table XXIII) and multiply by the average vehicle emission characteristics per mile. A 1967 vehicle was assumed to be the "average" car with the following characteristics:

Average Emission Characteristics

	g/mi.	% of Total
Unburned hydrocarbons	16.0	10.90
Carbon monoxide	120.0	81.75
Oxides of Nitrogen	5.8	3.95
Evaporated hydrocarbons	4.2	2.86
Particulates	.4	.27
Oxides of Sulphur	.4	.27
Total	146.8	100.00

These give traffic effluent loadings of from less than 10 to over 2,700 metric tons per square kilometer per year generated by from almost 40 to over 600 annual metric tons of effluent per kilometer of highway (Table XXIV, Fig. 16).

The railroad air effluent production data (Appendix I) does not take into account the railroads serving Norfolk-Portsmouth. Inasmuch as the Port of Hampton roads ships more than 33×10^6 tons of coal per year (Appendix I) a significant rail traffic through Norfolk must be generated. More than 71×10^6 tons of shipping (73,991 vessels) pushed through Hampton roads and over 7×10^6 tons (56,333 vessels) moved up and down the James estuary in 1970. The data available on effluent loadings seems low for this traffic. In addition no SO_x effluents are estimated (Appendix I). No information is available on numbers of flights from the three large military air bases. Since their combined traffic would

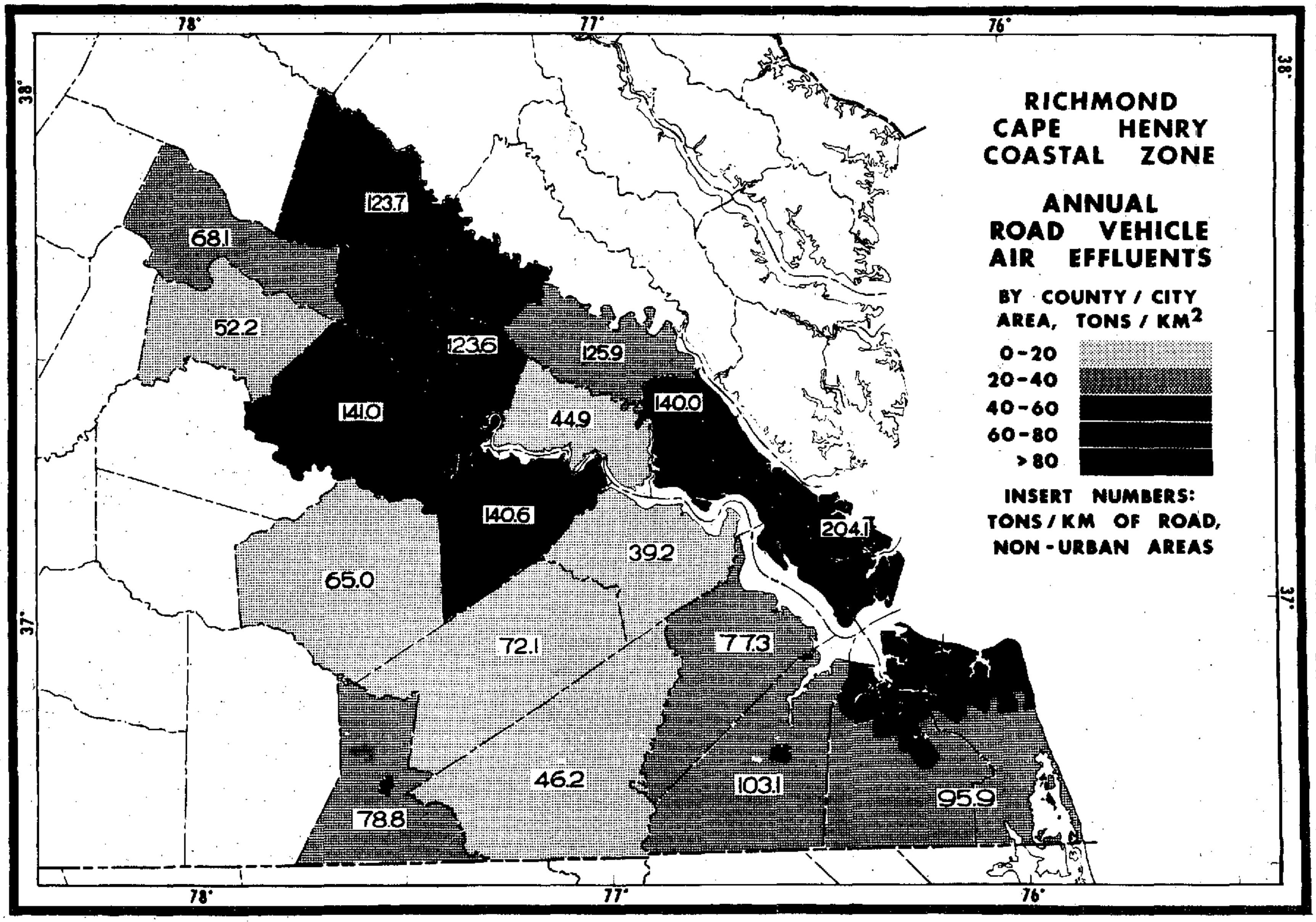


Fig. 16   Road vehicle air effluents by area and unit road length, 1970.

more than double the heavy jet traffic of the other fields, the estimates of air traffic effluents in Appendix I are probably less than one half actual. Overlays of line sources of pollution based on traffic densities should be coupled with the point and area sources to give source emission data for the air pollution module of RICHEL.

Electrical Generation

RICHEL is served by the Virginia Electric and Power Company (VEPCO), the principal generator and distributor of electricity and six Electrical Co-ops who distribute only (Fig. 17). VEPCO generates electricity in two hydro-electric plants just south of RICHEL in North Carolina and in six steam-electric generating plants, five of which are in RICHEL, another just west (Fig. 18). These burn either residual fuel oil or coal as follows:

Fuel Consumption for Power Generation in RICHEL

Location	Coal (tons/y)	Oil (1,000 gal/y)
Richmond	122,000	-
Chesterfield	1,318,000	284,512
York	676,000	396
Norfolk	125,000	270
Chesapeake	-	249,000

Source: Virginia Air Pollution Control Board, 1971

These produce over 300,000 tons of air effluents annually.

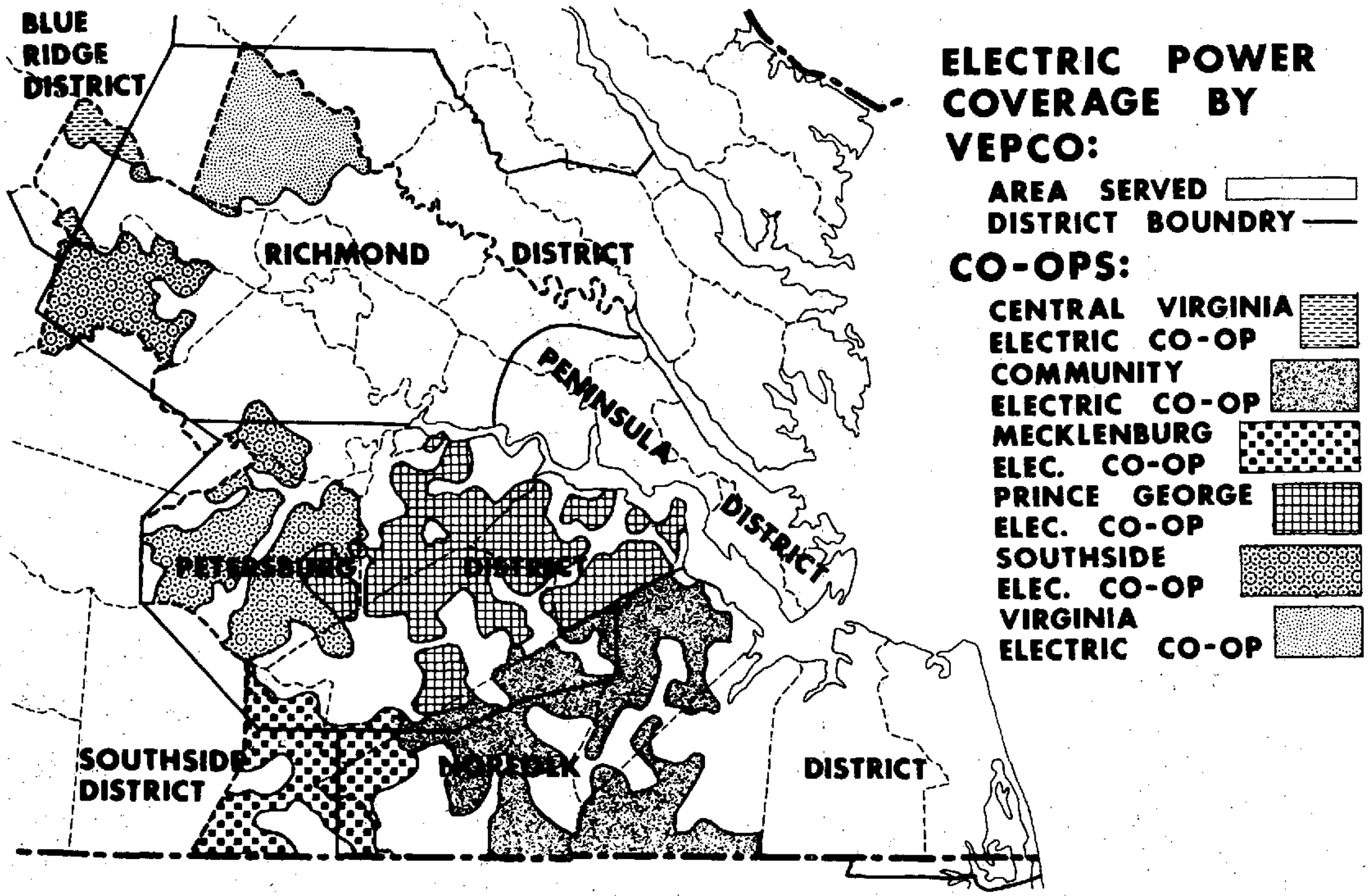


Fig. 17 VEPCO power districts and electrical co-op distribution areas.

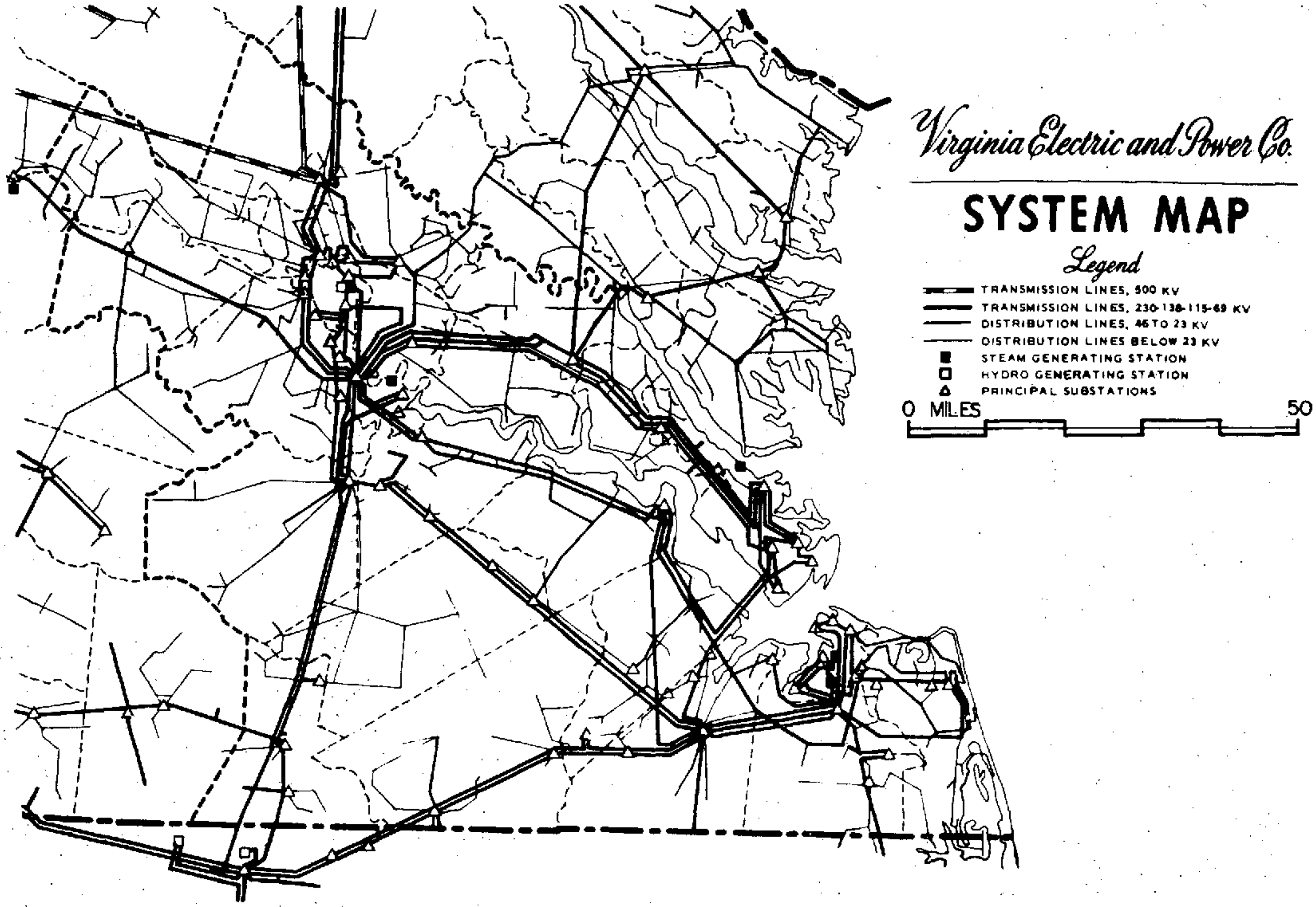


Fig. 18 VEPCO electrical power generation and distribution.

Air Effluents from Power Generation in RICHEL (tons/yr)

	Sox	Part	CO	HC	NOx	Total
Richmond-Chesterfield	77,121	114,934	726	927	27,897	220,705
Norfolk-York-Chesapeake	63,022	6,871	406	744	20,316	91,359
Total	140,143	120,905	1,132	1,671	48,213	312,064

Source: Virginia Air Pollution Control Board, 1971

These generating plants produced 11,857,031,000 KWH of power primarily for RICHEL in the year ending May, 1971, an increase of 6.91% over the preceeding year (Appendix I, Table XXV). Depending on the season, between 39 and 42% of this was for residential consumption, 16 to 25% for commercial; 12 to 36% for industrial; and 9 to 31% for public use (Table XXV). Resident consumption averaged 706.71 KWH during June, 1970 through Setperber, 711.67 KWH between November and the end of January, and 707.69 KWH for February through May, 1971. On the other hand, the Electrical Co-ops serving almost rural families exclusively averaged only 507.42 KWH per month for the same year (Appendix I). An urban resident of RICHEL burns 40.81% more electricity on the average than does a rural one. Overlays of power consumption based on these data when coupled with the land use will provide residential, commercial, and industrial energy requirements and heat losses.

Industry

Industry consumed 2,694,188,000 KWH in RICHEL in the year ended May, 1971 (Appendix I). It was the largest consumer of coal (ahead of utilities) and the second largest consumer of residual fuel oil (behind utilities).

Industrial Fossil Fuel Consumption

	Coal (1,000 t/y)	Distilled Oil (1,000g/y)	Residual Oil (1,000g/y)	(10^6+1 3/9)
Air District 5*	4.66	5,155	69,471	911
Air District 6	112.65	2,533	19,322	2,219
Total	117.31	7,688	88,793	3,130

*AD 5 = Planning Districts 20 & 21; AD 6 = Planning Districts 15 & 19

Source: Virginia Air Pollution Control Board, 1971

These generate 171,512 tons of pollutants as follows:

Industrial Air Pollutants (tons/y)

	SOx	Part	CO	HC	NOx
Air District 5	20,366	28,556	479	305	6,581
Air District 6	4,650	838	5,689	1,792	102,256
Total	25,016	29,394	6,168	2,097	108,837

Source: Virginia Air Pollution Control Board, 1971

The point sources of these are given in Fig. 19 and identified in Appendix I. These should be keyed to the locational grid for input into the air quality module of RICHEL.

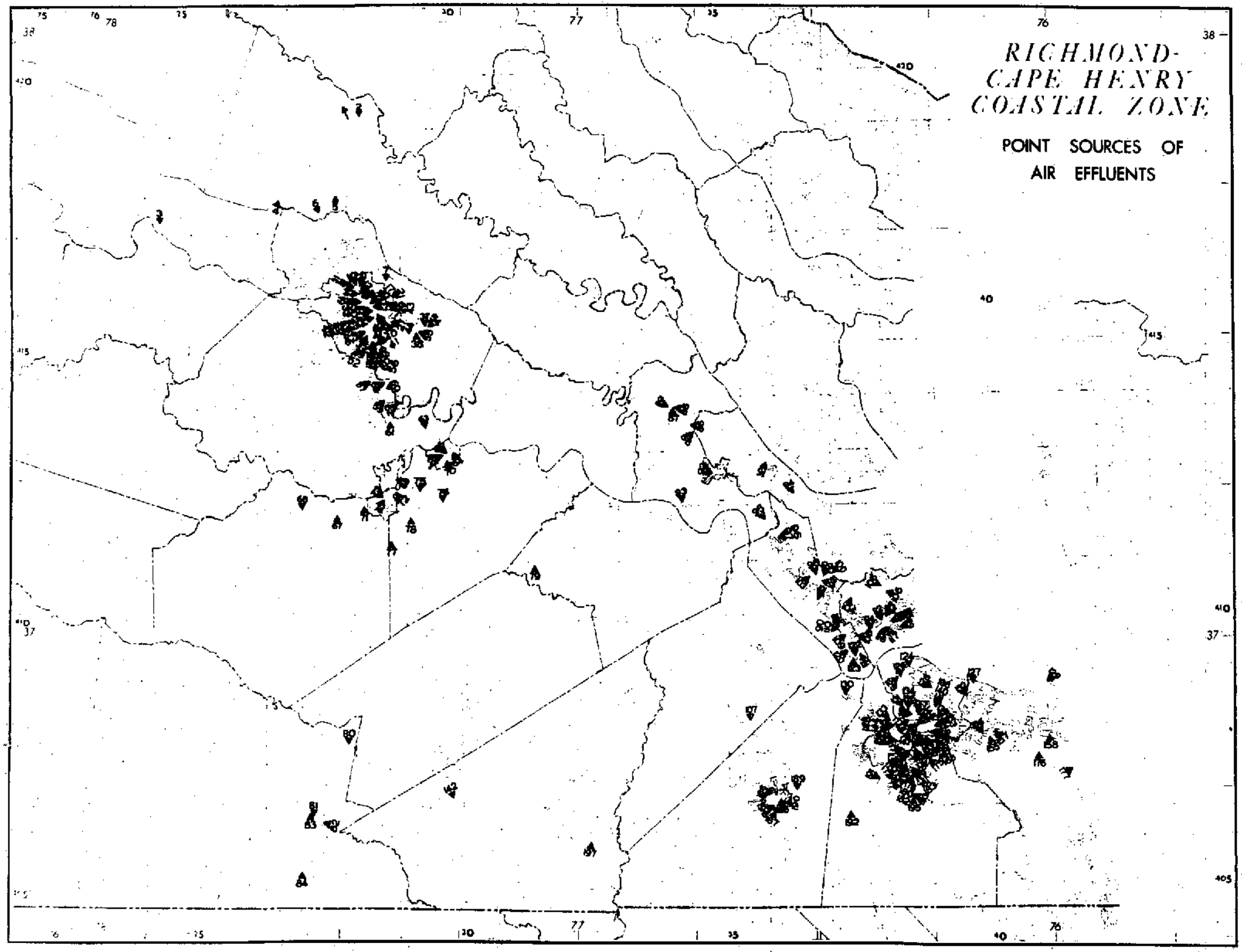


Fig. 19 Point sources of major air effluents; numbers refer to Appendix 1.

Residential & Commercial

The statistics on power consumption and effluent loadings for residential dwellings released by the Virginia Air Pollution Control Board and included in Appendix I are not correct. The numbers of dwelling units are often odds with the 1970 housing census (Table XV and XVI). More important, only one ton of coal was estimated to be burned per house per year and the estimates of natural gas consumption are only 2/3 of actual consumption (Appendix I, Table XXVII).

The results of the 1970 housing census are not yet available to accurately estimate the residential heating characteristics in RICHEL. However, there are obvious trends recognizable from the 1950/1960 data (Appendix I). Liquid fuel is the most common source of residential heating, having grown to between 55-60% of the urban and 70-85% of the rural houses by 1960. Fuel oil is followed by utility gas in those areas served by pipelines (Fig.20). Electricity is the chief method of water heating with rural areas substantially leading the urban ones. Electricity is followed by fuel oil and bottled gas in order. Cooking principally uses electricity with bottled gas a distant second. The substantially higher use of electricity in rural areas is indicative of the success of the electrical co-ops. If the Virginia Air Pollution Control Board's figures on utility, industrial and commercial consumption of natural gas are accepted as valid ($4{,}178 \times 10^6$ cu.ft.) then residential consumption of natural gas in RICHEL is $35{,}691 \times 10^6$ cu.ft. (Table XXVI) which represents 37.5×10^{12} BTU. There are 199.9×10^6 gallons of fuel oil consumed in RICHEL per year. This re-

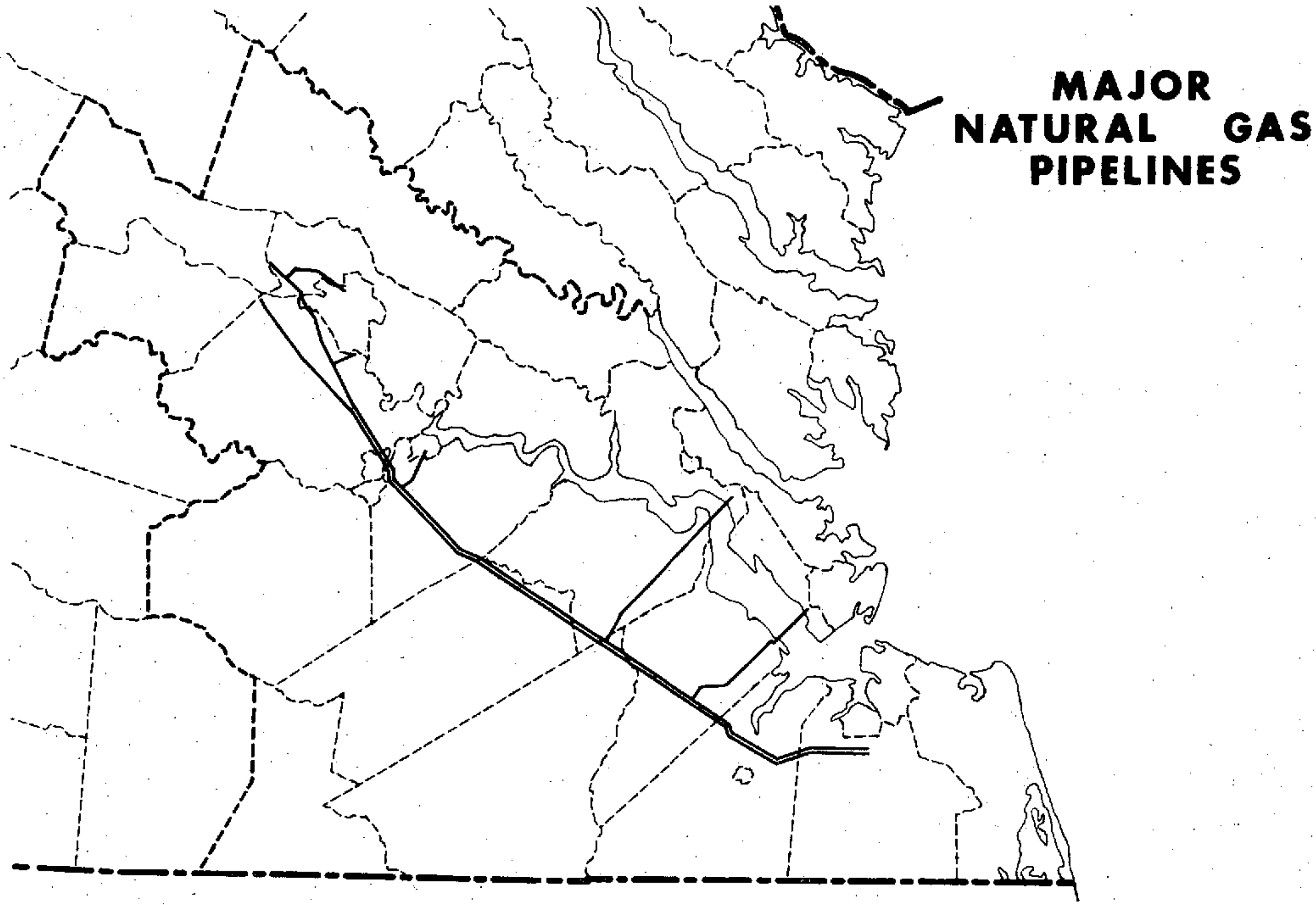


Fig. 20 Natural gas distribution, major pipelines.

presents 27.8×10^{12} BTU. Gas and oil probably represent more than 95% of the fuel use for residential heating in RICHEL. The remainder is chiefly coal.

Mr. B. Reams (Reams Coal and Oil, Richmond) has 45 years experience in fuel distribution. His rule-of-thumb for coal-heated houses is one ton per room plus one ton for the house per heating season (November-March). The average house size in RICHEL is just over five rooms: This house requires six tons of coal per year. Reams' experience with multi-unit dwellings indicates that six unit apartments more than 20 years old require about 38 tons per heating season, very nearly the same per unit as for single unit five room housing. A 20 year old 12 unit apartment requires 71 tons, again nearly the same per unit as residential. Apartments built within the last five years which burn coal require only 2/3 the fuel than do older apartments. However, there are few such buildings. Therefore, six tons per housing unit is accepted and the Virginia Air Pollution Control Board estimates of coal and effluents should be increased accordingly.

Commercial use of fuel is given below from data supplied by the Virginia Air Pollution Control Board (Appendix I).

Commercial Fuel Consumption

	Coal tons/y	Dist. Oil 1,000g/y	Resid. Oil 1,000g/y	Nat. Gas 10^6 ft^3/y	Total
Air District 5	40,700	2,564	1,790	551	45,605
Air District 6	9,000	190	2,445	10	11,645
Total	49,700	2,754	4,235	561	57,250

These produce effluents of the following quantities:

Commercial Fuel Combustion Effluents

	SOx	Part	CO	HC	NOx	Total
Air District 5	1,041	295	109	43	418	1,906
Air District 6	15,133	1,343	198	209	3,780	20,663
Total	16,174	1,638	307	252	4,198	22,569

Additional sources of air effluents in RICHEL arise from refuse disposal. Over 5,800 tons of effluents are produced by incineration and over almost 5,400 tons by open burning (Appendix I).

Area Summation

The compilation of air effluent loading by county and major city for RICHEL (Fig. 21, Appendix I) for non-vehicle sources are taken from Virginia Air Pollution Control Board data. They are not corrected for the increased housing production or for other discrepancies discussed above. The values run from more than 4,000 lbs. per person in Chester-

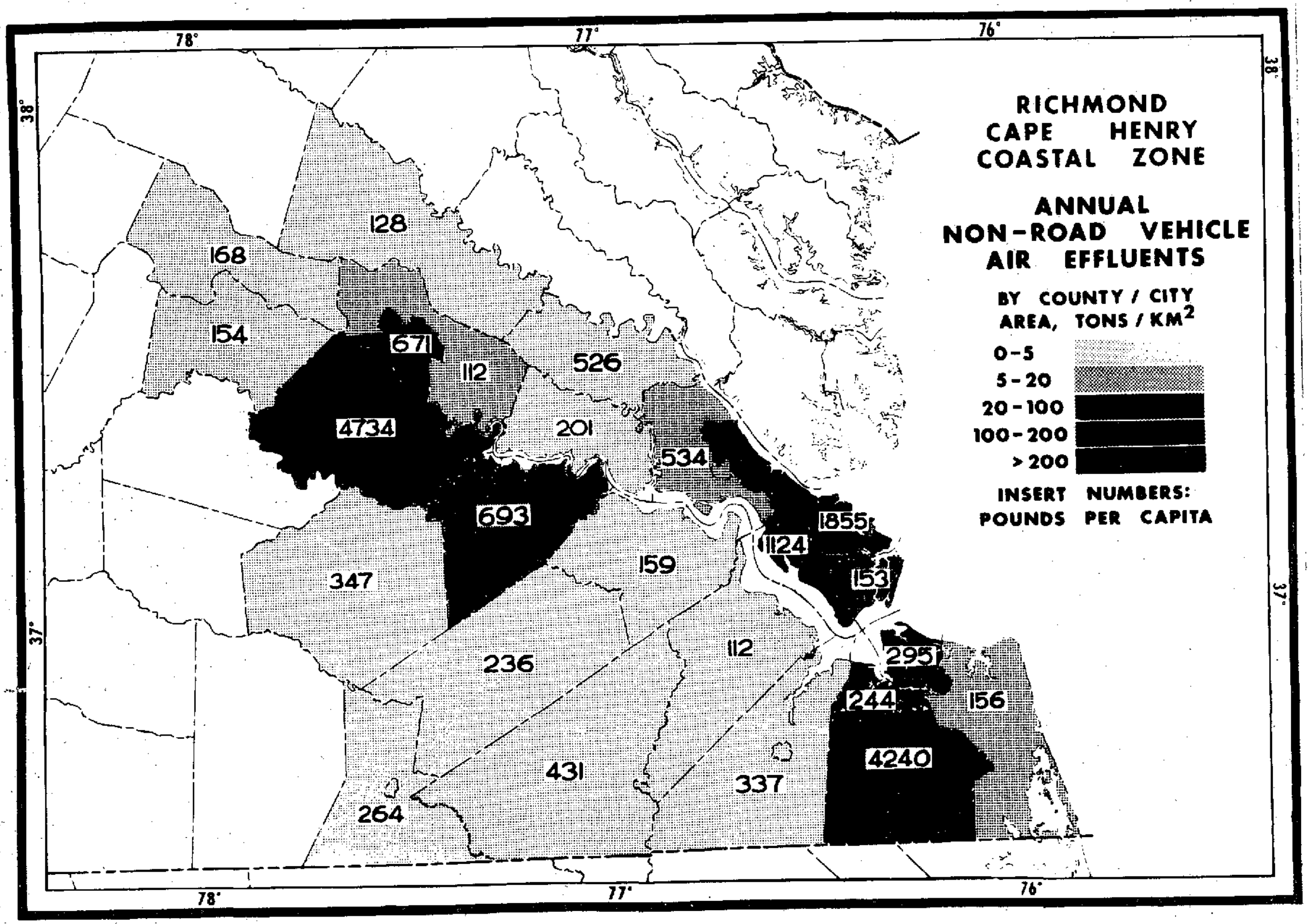


Fig. 21 Air effluents from non-road vehicle sources; effluent densities by area and per capita.

field and Chesapeake counties to as low as 110 lbs per person in Isle of Wight and Henrico counties. Overlays of area air emission characteristics should be compiled from the data in Appendix I for input into the air pollution module of RICHEL.

Additional Sources of Air Effluents

Field and forest burning, natural or intentional, add substantially to the air quality background, especially of particulate matter. There were 1,810 fires in Virginia in 1970, 1094 of which occurred in the period February through April (Appendix I). These accounted for 56% of the acreage consumed during the year. The average fire is 5.4 acres although on April 10, 1969, 10 fires occured which ranged in area from 125 to 592 acres, 20% of the entire burn for 1970!

EPA estimates (Buckholtz, pers. comm.) that the following types of emissions are generated by open burning:

Air Emissions from Open Burning (lbs/ton burned)

	Agricultural Field	Brush	Woods
Particulates	17	17	17
CO	100	60	50
Hydrocarbons	20	20	4
NO_x	2	2	2
Total	139	99	73

The Virginia Forestry Service estimates (Bartholomew, pers. comm.) that in the south the particulates produced by a forest fire would range from 17 lbs/ton burned for a back fire to 58 lbs/ton for a head fire. A mature pine forest 20 to 30 years old has 15-20 tons per acre; a hard wood forest 10 to 15 tons/acre; and the Great Dismal Swamp up to 50 tons/acre The land use distinctions in forest type now become increasingly important as an estimate of air emissions from a forest fire. The emissions from these fires must be incorporated into background air effluent loadings for the air quality module of RICHEL.

Surveillance

Virginia's State Air Pollution Control Board was established in 1966 along lines parallel with the State Water Control Board. The state is divided into four areas each of which has a representative although no field offices are maintained (Appendix I). Their primary responsibilities are to investigate and verify complaints of air pollution and to work with the alleged violators to achieve voluntary compliance with the air pollution rules and regulations. Howard, et al, 1970, examined the state air quality law and reached the following conclusion:

"Unlike the Water Control Law, there is no statement of purpose of the Air Pollution Control Law from which one can establish the mandate of the SAPCB; in fact nowhere in the law is there a description of the obligation of the SAPCB to maintain air quality. The law does not provide for the issuance of certificates; therefore the Board is limited essentially to "after-the-fact" enforcement of air quality rules and regulations. Power is provided for review of plans, specifications, etc., when there is reason to believe an owner "is causing, or may be about to cause, an air pollution problem," but such instances must be brought to the attention of the Board, as there is no requirement for review.

The most explicit language of the law obligates the Board to give prominent consideration to factors other than the presence of contaminants in the air. That the primary purpose of the law is to maintain clean air is not at all clear. It is also not clear that the enforcement and appeal procedures and the penalties, while virtually the same as those in the Water Control Law, are enforceable for air pollution when all the considerations, cited above, are included in making a decision.

The Executive Secretary has made clear that the Board's intention is to effect "voluntary compliance" with state air quality rules and regulations rather than resort to courtroom proceedings for enforcement. This approach is the same as that followed by the SWCB. As the first rules were published only in August, 1969, the efficacy of the "voluntary compliance" approach has not been tested clearly.

Rules have now been established for particulate matter and odorous discharges as well as exceptions and variances to these rules. The categories for which the rules have been established are smoke or other visible emissions; open burning, dust, and fumes; odor; dust emission from indirect heating furnaces; and air quality standards for gaseous pollutant emissions, including sulfur oxides and combustion installations and process industries. To be prepared are rules for motor vehicle emissions and incinerators.

Except for automotive emissions, the rules are being established for relatively prominent point sources of pollution. Except for open burning most of the sources are easily identified and monitored, i.e., they are, for the most part, factories, power plants, incinerators, and apartment buildings. An effective surveillance and enforcement program should be facilitated by the prominent, fixed nature of the pollution sources.

Emissions problems originating with automobiles would seem to be complicated by the highly dispersed, mobile nature of the sources of pollution. While ambient air standards can be established, enforcement by the State will be hindered because of the collective responsibility for violation of these standards. Some sort of stringent pollution abatement equipment, inspection, and enforcement requirements for automotive devices will be needed, and such requirements would likely pose a severe test of the equivocal air quality objectives of the State Air Pollution Control Law.

While the Air Pollution Control Law does provide for a comprehensive state plan for air quality, the Executive Secretary has expressed the intention of permitting air quality standards to be set by localities, subject to approval by the Board. Whether localities will be able to cope effectively with entrenched vested interests remains to be seen. Indeed, were the Board to take more of the lead, the seeming weaknesses in the law establishing the Board raise some question about what ends it could effect."

Virginia operates more than 130 stations which monitor some aspects of air quality, if only dustfall (Appendix I, Fig. 22). The Federal network has four 24-hour gas sampling stations in RICHEL and five sampling suspended particulates (Appendix I). The availability of both Commonwealth and Federal data at present are torturous; six months for Virginia, a year or more for Federal. The data in Appendix I from the Virginia

Air Pollution Control Board was cheerfully supplied as soon as it had been certified. Although there are many internal inconsistencies and a few glaring errors, it is a much needed beginning. The industrial and commercial data were generated by a questionnaire (Appendix I) the results of which were to be kept confidential on an individual basis for any particular fuel consumer.

Data from these monitoring stations will provide a means of validating the predictions of the air quality module of RICHEL.

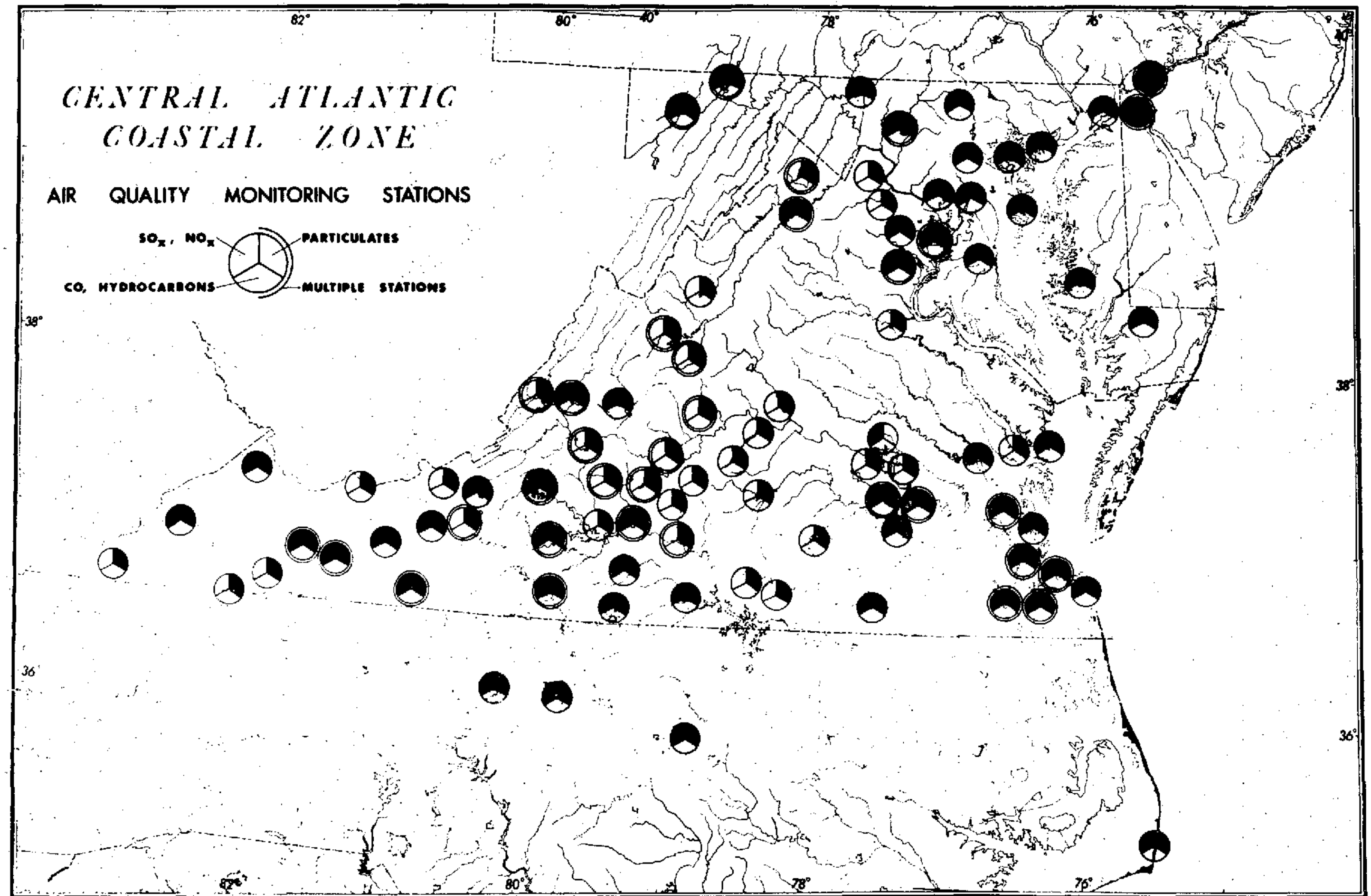


Fig. 22 Virginia and Maryland air quality monitoring stations; North Carolina stations are part of the Federal network.

Water Effluents

The principle effluent contributors to water are discharges of industrial and utility wastes; municipal and institutional partially treated sewage; and agricultural pollutants consisting of animal wastes, fertilizer, and pesticides. The quality of the water in the James River just above Richmond is generally good (Table XXVII). The bulk of the Richmond municipal waste is discharged into the river below the fall line. There the water quality is appreciably degraded and oxygen is markedly reduced. The Appomattox River above Lake Chesdin is generally good. Below the lake and adjacent to the cities of Petersburg and Colonial Heights the river has been the site of several fish kills (VDCED, 1971).

The James Estuary below the confluence of the Appomattox in the vicinity of Hopewell receives large quantities of both industrial and municipal wastes which depress the dissolved oxygen as far east as Weyanoke Point (12 miles). Between Weyanoke Point and the Nansemond River only local problems exist adjacent to small sewer outfalls (VDCED, 1971).

The Nansemond River and the James Estuary below their confluence are severely degraded due to industrial and municipal waste discharges. These conditions continue through Hampton Roads and along the southern end of Chesapeake Bay to Cape Henry. Almost this entire area has been condemned for shell fishing.

Industrial and Utility Effluents

There are 17 major industrial or utility users of water on the James River in the Hopewell and Richmond Area and almost 20 in the Norfolk area (Fig. 23, Appendix J). The production of chemicals and related products uses the largest amount of water, 186.86 mgd from both river and ground in the middle James between Richmond and Hopewell (Appendix J). An additional 17.01 mgd are used in chemical industries on the lower James around Norfolk. These quantities are below the estimates of the Virginia Water Control Board of more than 250 mgd (VDCED, 1971) but inasmuch as they are based on data supplied by the companies themselves under Federal surveillance the data are considered reliable. They produce the following effluents:

Chemical Industrial James Estuary Effluent Loadings[1]

	BOD	COD	Total Solids	P	N
Middle James[2]	54,823	33,586	18,122	534	13,880
Lower James	5,894	21,711	555,104	175	1,001
Total	60,717	55,297	573,226	709	14,881

[1]Pounds per day rounded to nearest pound
[2]Data incomplete - see Appendix J

Source: U.S. Army Corps of Engineers, Norfolk, Va., 1971

The second largest user of water is the paper manufacturing and processing industry which uses 28.9 mgd, largely confined to the middle James, which produces effluents as follows:

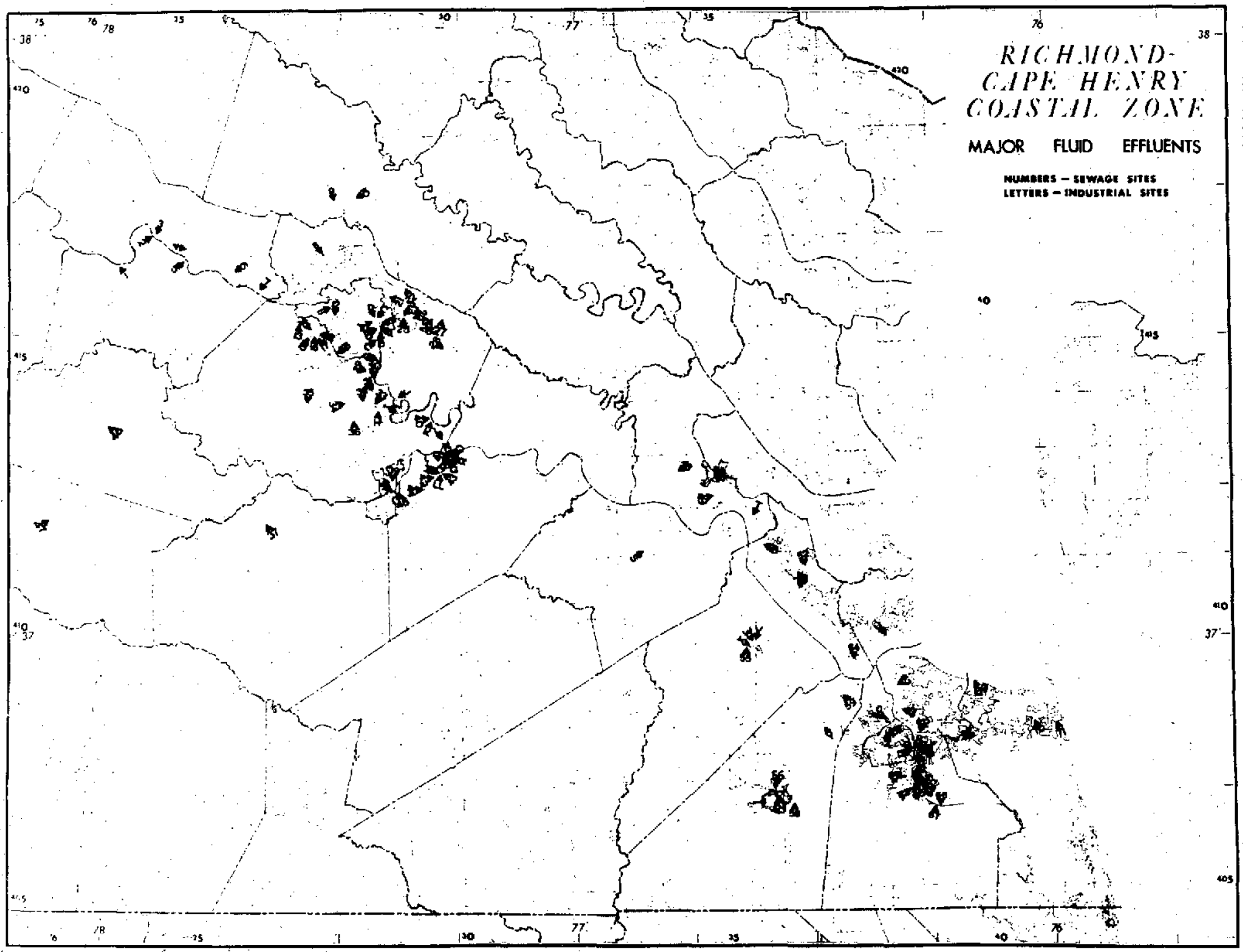


Fig. 23 Industrial Municipal and Institutional Waste Discharge Localities

Paper and Food Industrial James Estuary Effluent Loadings[1]

	BOD	COD	Total Solids	P	N
Middle James (paper)[2]	44,802	162,355	219,555	1,196	10,687
Lower James (food)	9,360	14,440	60,047	302	694

[1]Pounds per day to nearest pounds
[2]Data incomplete - see Appendix J

Although food processing is largely confined to the lower James and uses only 1.625 mgd it produces major effluents.

James River Effluents per Gallon Process Water
(lbs.x10^{-6})

	BOD/gal	COD/gal	TS/gal	Nutrients/gal
Chemical	299.3	272.6	2,825.6	76.9
Paper	1,550.2	5,617.8	7,597.1	411.2
Food	5,760.0	8,886.2	36,952.0	612.9

The electrical generating utilities use more than 4,500 mgd of surface water for cooling. A figure of 3,800 BTU per KWH is used for fossil fueled plants and 6,400 BTU per KWH for nuclear plants, assuming 38% efficiency for the former and 33% for the latter. Power plants in RICHEL add 20,521.6x10^6 BTU per hour to the James and York rivers as follows:

Cooling Water Requirements and Thermal Loading

	MGD	kwx10^3	BTU/hrx10^6	F°/gal
12th Street Richmond	147	77.5	294.5	6
Chesterfield	1,079	1,383	5,255.4	14.6
Portsmouth	516	597	2,268.6	13.2
Reeves	205	263.5	1,001.3	14.7
Yorktown[1]	288	340.9	1,295.4	13.5
Surry[2]	2,314	1,626.0	10,406.4	13.5
Total	4,549	4,287.9	20,521.6	

[1]Discharged into York Estuary
[2]Nuclear, not yet operational

Source: Corps of Engineers, Norfolk District

These industrial and utility effluent point sources should be input to the estuarine circulation module.

Municipal and Institutional Effluents

The Virginia Department of Health recommends that all new waterworks meet minimum design criteria of 100 gpd/capita. It is the view of the Virginia Department of Conservation and Economic Development that minimum per capita water consumption will reach 138 gpd in 1980 and 168 gpd in 2000 (VDCED, 1971). This contrasts with the present water consumption of the United States: The average household uses between 30 and 80 gpd:

Water Use in the United States, 1964

Home	Amount(gal)	Industry	%
Washing dishes	10	Chemical & Allied	25
Flushing a toilet	3	Primary Metal	22
Shower Bath	20-30	Petroleum & Coal	20
Tub Bath	30-40	Paper & Allied	19
Washing machine load	20-30	Food & Allied	4
		Other Manufacturing	10

Source: U.S. Department of Interior, Environmental Report, River of Life, Water: The Environmental Challenge

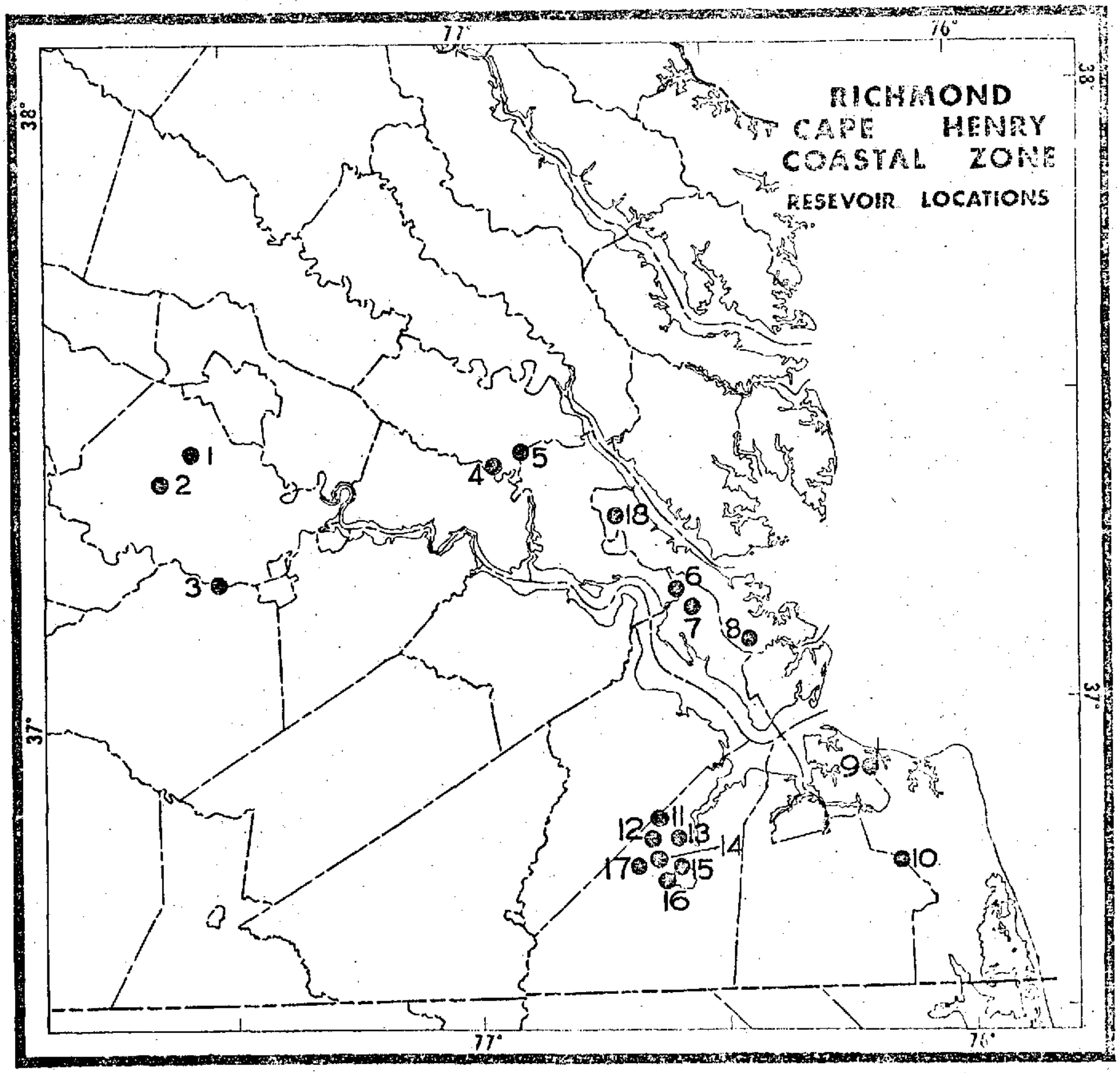


Fig. 24 Surface Water Impoundments; see Table XXVIII

The VDCED estimates 50 gpd is the average rural consumption from the private water systems. Using 80 gpd. for urban and 50 gpd. for rural, the 1970 population of RICHEL uses 170.1 mgd of water in a population that is 73.2% urban. They are served by municipal and private waterworks with capacities which presently exceed 300 mgd (Appendix J, Fig. 24, Table XXVIII). However, this capacity is not evenly spread; the most rapidly expanding cities of Virginia Beach and Chesapeake buy their water from Norfolk whose reservoirs are becoming eutrophic (Stedfast, pers. comm.). Projected public water supply requirements to the year 2020 forecast a need for 903.3 mgd for RICHEL (Table XXIX).

RICHEL is served by municipal and institutional sanitary sewerage systems with a capacity of 142.877 mgd (Appendix J) which serves 76.77% of the population. Over 75% of this sewage receives primary treatment only; 24.9% secondary and only .1% tertiary (Appendix J). Using a value of 0.17 pounds of BOD_5 per capita for primary treatment, 11 pounds of BOD_5 for secondary treatment, and .0525 pounds of total nutrients (P+N) per capita effluent loadings for RICHEL sewage treatment systems are as follows:

Municipal and Institutional Effluent Characteristics (poundsx1,000 per day)[1]

Planning Districts	Primary[2] BOD$_5$	Primary[2] Tot. Nutr.	Secondary[3] BOD	Secondary[3] Tot. Nutr.
15	34.8	16.6	1.60	3.3
19	9.5	4.5	.26	0.5
20	50.9	24.3	4.47	9.2
21	19.5	9.3	2.27	4.7
Total	114.7	54.7	8.60	17.7

[1]% served primary and secondary from Appendix J, 1970 population

[2].11 pounds per capita based on 35% reduction of .17 pounds per capita per day; .0525 pounds of nitrogen plus phosphorous (VDCED, 1971)

[3].0525 pounds per capita based on 85% reduction; same nutrient loading

Marcus and Whipple (1970) report that gross water pollution (prior to treatment) grows at a rate of about 55% of the population growth rate. In an area of rapidly expanding urbanization such as RICHEL the consequences for both surface and subsurface water could be catastrophic.

Overlays giving per capita effluent production and character by urban and nonurban for each census tract or SMSA should be prepared together with discharge routing. These should be related to the lccalizer grid and estuarine circulation module.

Agricultural Effluents

The effects of agriculture on water quality other than erosion and increased sediment load stem from fertilization, pesticides (and related treatments), and animal waste production.

There were 55,307.44 tons of nutrients added to RICHEL croplands during the year ending June 30, 1971 (Appendix J). This was an increase of 7.23% over the preceeding year and an average of 176.7 pounds per acre of cultivated land. There is little agreement as to what constitutes over fertilization which could cause increased nitrogen or phosphorous values in surface or ground water leading to eutrophication (Aldrich, et al, 1970). However, the fact that the city of Norfolk reservoirs in Chesapeake County have lush algal blooms may be in part due to over fertilization. Unfortunately, there is little information on specific applications other than the average cropland loadings given in Appendix J. Water quality records are too sketchy to be used for corroboration, especially with urbanization also providing increased nutrient sources.

There is no way of determining the quantity or nature of pesticides or herbicides used in Virginia (Appendix J). Inasmuch as the 1964 census of agriculture is the most recent reliable data on the number of acres dusted or sprayed (but not the quantity per acre or type of application) the data are included as a basis for eventual comparison (Table XXX). It was the first hand observation of the authors that airborne spraying during the summer of 1971 was more than twice as extensive as in the past in an effort to prevent or control corn blight.

The Virginia Department of Agriculture and Commerce (VDAC, 1971) found pesticides in 24% of surface water sample although none exceeded the standards set by the Department. Residues of DDE, DDD, DDT and PCB's were also found in shellfish although within "acceptable" limits. However, an appreciable number of samples of fruits, vegetables, and feed exceeded the pesticide residue standards between 1969 and 1971 (VDAC, 1971).

Until the 1969 census of agriculture is released only estimates of animal populations are available. The National Livestock Feeders Association has established the following animal equivalent (news release, 1971): 1 animal unit BOD = 1 beef steer; or .7 dairy cows; or 4.5 butcher pigs; or 12 sheep; or 35 feeder pigs; or 55 turkeys; or 180 laying hens; or 290 broilers. It is therefore important to know the particular type of feedlot and animal density as a land use type.

There are no feed lots <u>per se</u> in RICHEL. However, several counties have appreciable animal populations which could cause local ground water pollution or reservoir eutrophication (Table XXXI) and a livestock loading facility was opened at the Richmond Deep Water Terminal in 1970.

Overlays of fertilizer/pesticide density application can be prepared knowing crop type and seasonal application practices. Monitoring the drainage system for nutrients and pesticide breakdown produces should provide algorithm upgrading.

Transportation and Recreation Effluents

Water pollution from ship and boat traffic on the James Estuary and her tributaries comes from accidental petroleum spills as well as chronic leakage and from refuse disposal. Almost 74,000 vessels called at Hampton Roads in 1970. The principal imported cargo was petroleum products (Appendix I). Over 56,000 trips were made up the James to either Hopewell or Richmond with oil remaining the chief cargo going upstream. The opportunities for a major spill within RICHEL are obvious. If each vessel on the James or in Hampton Roads released only one gallon of oil per trip from leaking packing glands, a substantial pollution problem already exists. The amount of refuse and effluents disposed of in the estuary can only be estimated.

There are almost 500 pleasure boats on the James which generate an estimated 2,800,000 man-boating days per year (VDCED, 1971) as given below:

Recreational Boating on James and Tributaries, 1971

Nansemond River	25
Newport News Creek	50
Deep Creek	150
Jamestown	50
Pagan River & Jones Creek	20
Appomattox (Hopewell, Colonial Heights, Petersburg)	75
Richmond (James above Hopewell)	120
Total	490

Source: Clean Water: Affluence, Influence, Effluents; NASA Langley Research Center & Old Dominion University

The accumulated fuel spills from these recreational activities can only be surmised. Remote sensing coupled with water sampling can supply the data needed to monitor both hydrocarbon spills and chronic leakage. The estuarine circulation module could predict the fate of a spill.

Solid Waste Disposal Effluents

The refuse of living ends up in a dump. The dump generates decomposition gases as well as effluents from spontaneous and controlled burning. In addition leachates from the dump often end up in the ground water.

For the first six months of 1971 the City of Norfolk collected over 108,000 tons of trash and garbage about 12% of which was burnable

(Table XXXII). This is 3.2 lbs. per capita per day for the City. Significant increases of waste occur during March through June. The majority of these materials end up in Mount Trashmore a sanitary land fill in Virginia Beach City and shared by that municipality. In three years 6.5 acres have been filled 60 feet thick. To date no adverse effects have been noted in the ground water (Parsons, 1971).

The per capita solid waste generated by the City of Norfolk is mirrored by an urban fringe county, Henrico, which averaged 3.4 lbs. per capita per day (Table XXXIII). The per capita production of solid waste coupled with the population data should provide information for monitoring, managing, planning.

Surveillance

The State Water Control Board was established in 1946 to exercise primary responsibility for water quality in the Commonwealth. The staff of the Board are organized into three divisions: Technical Service, Pollution Abatement, and Enforcement. The Pollution Abatement Division is divided into five administrative regions. RICHEL lies within region 1 and 5 (Appendix J).

The powers of the Board are extensive and include the issuance of discharge certificates; establishment of water quality standards rules, regulations and policies, and conducting investigations and inspections.

Howard, et al, 1970, have judged the performance of the SWCB as follows:

"Virginia is one of the last two states (the other is Iowa) to have its water standards approved by the Department of the Interior. In December, 1969, Virginia agreed to include a non-degradation clause along with new standards. This clause works to restrict the SWCB in its interpretation of "reasonable intended use" of state water. Acceptance of the clause probably means that the Board will have to abandon its practice of studying discharge requests on an individual basis for some kind of regional water quality managment. Since many discharges will be treated to a greater extent than the "reasonable expected use" of the surrounding waters would have required, the Board has maintained this is tantamount to treatment for treatment's sake. While future water quality does seem now to be better protected, the expense of meeting these additional standards will certainly be considerable--an additional $100 million or so, according to the Board's Executive Secretary. How much of this additional expense will be met by federal funding is unclear.

Until the capacity for planning water or environmental quality on a regional, e.g., river basin or air space, basis is realized, the closest we may come to effective management of environmental quality may be federally approved standards for all states for an increasing number of sources of pollution. This approach is particularly likely to be effective if it is tied to a funding program to provide the financially hard-pressed states the resources to meet the standards to which they have agreed. The advantages of regional organizations would seem to be the opportunity for more refined and ambitious planning within an ecologically defined region, but the problems of achieving effective authority which transcends present political boundaries continue to be formidable.

Virginia would seem to have an extensively developed capability for dealing with the quality of state waters. In practice, the Board has not felt the need to invoke all of its powers, but has relied instead on the "voluntary compliance" of owners dischargingwastes. Thus, while hearings have been held, special orders issued, and injunctions served, solutions acceptable to the Board have been worked out without the need to resort to courtroom proceedings. In part, this approach has been possible because of the Board's interpretation of "reasonable use" for state waters. For example, a higher level of degradation has been accepted for waters which are not intended to be part of a domestic water supply. In addition, there is no required minimum level of treatment. All sources of discharge are judged individually as to their effect on surrounding waters. If the cumulative effect of several owners seriously degrades the water environment, then the requirements of water treatment are re-established for each owner, individually.

This approach is likely to be inadequate if industrial and population growth continue to accelerate. The Board down not seem inclined to set minimum standards of treatment sufficiently stringent to assure future water quality as the growth of the Urban Corridor continues."

REMOTE SENSING AS A COST EFFECTIVE DATA BASE FOR COASTAL ZONE MANAGEMENT

Goodell et al (1971) found that remote sensing could supply a source of data which was unique for those agencies with responsibilities in the coastal zone. However, they also concluded that few agencies currently had the expertise to utilize adequately even aerial photography. Data presently used in management and regulation is primarily being acquired through licensing, certification, registration, permit issuance, and the Bureau of the Census. What environmental monitoring is carried on is based on non-continuous and non-synoptic surface sampling. Goodell et al (1971) concluded that black and white photography at a scale of about 1:20,000 would meet most data requirements for most agencies. The second-most important sensor is false color infrared film. These findings paralleled those of Wilson (1969) who studied sensor capabilities for the recognition of the characteristics of natural and cultural features.

Ulliman (1970) states that the cost of acquiring existing ASCS black and white photography is as follows:

Cost of ASCS Photography (1968)

	Contact Prints	Enlargements		
Approximate Scale	1:20,000	1:16,000	1:12,000	1:8,000
Size (in.)	9 1/2x9 1/2	14x14	18x18	24x24
Price print	$1.25	$2.50	$2.75	$3.50
Price/mi^2	.14	.20	.22	.39

If up to date photography is not available, low altitude black and white photography may be contracted for at approximately the following costs (Ulliman, 1970):

Approximate cost per square mile for contract aerial photography, by size of area and photo scale[1]

Area in square miles	Aerial photo scale 1:20,000 or 1,667 ft./in.	1:15,840 or 1,320 ft./in.	1:12,000 or 1,000 ft./in.	1:9,600 or 800 ft./in.	1:7,920 or 660 ft./in.
25	$35.00	$40.00	$42.00	$45.00	$50.00
50	20.00	22.00	26.00	30.00	45.00
100	12.50	15.00	20.00	25.00	35.00
200	8.60	13.80	18.00	20.00	27.00
400	7.50	12.00	15.00	17.00	23.00
800	6.20	9.90	12.00	14.00	18.00
1,500	5.10	8.20	10.00	12.00	17.00
2,500	4.80	7.70	9.00	11.00	16.00
5,000	4.20	6.70	8.00	10.00	15.00

[1] Prices listed represent averages from several sources, and thus do not apply to any specific area. In all instances, stereoscopic coverage on black-and-white (panchromatic) film is assumed. Cost of ground control work and preparation of maps from the photographs are NOT included.

High altitude photography (above 18,000 ft.) at a scale of 1:60,000 or greater can only be obtained through a Federal Agency, usually the Department of the Interior, who distributes NASA imagery through its EROS facility at Souix Falls, South Dakota. The cost of a 9"x9" transparency of false color infrared is about $8.00 or about $0.016 per square mile (1:120,000). The cost of obtaining the full photographic coverage of RICHEL at this scale would be only about $100. Whatever are the limitations for the recognition of terrain or cultural features at this scale, and there are many, the price is modest for assessing the following environmental characteristics (from Mission 144):

1. Point sources and extent of air pollution plumes (stacks and forest fires)

2. Point, area sources, and extent of water turbidity including oil spills

3. Extent and health of wetlands

4. Extent and health of ground cover

5. Soil erosion and sediment transport

6. Marine erosion, dredge and fill, spoil disposal, siltation, and water shoaling

7. Mining, construction, and earth moving

8. Wave direction and wave length

9. Longshore current direction and general estuarine circulation patterns

10. Land-use down to Level II (Table III) and in some categories to a further level

For these broad assessments of the Earth's surface this high altitude photography is highly cost effective. It is unexcelled as an aid to understanding environmental dynamics which occur with geometric scales of up to hundreds of square miles and with time scales of less than an hour. However, for the detailed planning and strategy of resource management, large scale photography must be coupled with ~~low~~ high altitude photography at much smaller scales in order to resolve the detail required for most data bases.

It is doubtful that ERTS A satellite photography will be of much value, however small the cost per square mile, in resource management. Its resolution of about 100 meters is too large for either land use mapping at any but LEVEL I (Table III) or for recognition of any but the largest scale environmental phenomenon such as regional circulation patterns in the earth's fluid envelope. At these scales interest is primarily to the scientific community or to Federal agencies charged with the broadest aspects of resource allocation.

SUMMARY

An environmental computer model is proposed for about 17,000 square kilometers of the coastal zone of southeastern Virginia between Richmond and Cape Henry including the James Estuary using remote sensing as the source of the land use data base. RICHEL includes the southern end of Virginia's Urban Corridor and contains almost 39% of her population. The model could be used to develop planning strategy and public policy alternatives in an area that is already heavily impacted and which is forecast to have large increases in population over the next 30 years.

The model is developed around the hydrologic cycle with two major data banks consisting of climate and land use. Water and air quantity and quality are developed as a function of land use. The power, water, and air resources required in RICHEL are identified.

The impacts of population on the environment of RICHEL are quantified in terms of human activities which result in interference with the hydrologic cycle, accelerated erosion, and effluent generation.

High altitude photographic transparencies of 1:120,000 cost about \$.016 per square mile. This is considered highly cost effective for monitoring land use inventory and the intermediate scale physical processes which affect the environment. However, remote sensing will not eliminate the data base in present use by agencies charged with resource allocation and management in the Coastal Zone. Remote sensing is however a valuable supplement.

TABLE 1

RICHEL
COUNTIES, INDEPENDENT CITIES, TOWNS

	AREA[1] Sq.Miles 1969	POPULATION[2] 1960	1970	Persons per sq.mi. 1970
Planning District Fifteen				
Richmond Regional PDC		461,993	547,542	
Charles City County	204.00	5,492	6,158	30
Chesterfield County	468.52	71,197	76,855	164
Goochland County	295.00	9,206	10,069	34
Hanover County	471.00	27,550	37,479	80
Ashland	(1.00)	(2,773)	(2,934)	2,934
Henrico County	234.40	117,339	154,364	659
New Kent County	221.00	4,504	5,300	24
Powhatan County	272.00	6,747	7,696	28
Richmond City	39.93	219,958	249,621	6,252
Planning District Nineteen				
Crater PDC		141,471	161,059	
Dinwiddie County	506.36	22,183	25,046	50
McKenney[3]	(0.74)	(519)	(489)	661
Greensville County[4]	302.00	16,155	9,604	32
Prince George County	298.26	20,270	29,092	98
Surry County	306.00	6,220	5,882	19
Claremont	(1.57)	(377)	(383)	244
Dendron	(1.08)	(403)	(336)	311
Surry	(0.79)	(288)	(269)	365
Sussex County	496.00	12,411	11,464	23
Jarratt	(1.27)	(608)	(591)	938
Stony Creek	(0.63)	(437)	(430)	683
Wakefield	(0.42)	(1,015)	(942)	2,243
Waverly	(0.60)	(1,601)	(1,717)	2,862
Colonial Heights City	8.15	9,587	15,097	1,852
Emporia City	2.39	5,376	5,300	2,218
Hopewell City	11.30	17,895	23,471	2,077
Petersburg City	8.97	36,750	36,103	4,025
Planning District Twenty				
Southeastern Virginia PDC		666,841	769,371	
Isle of Wight County	360.00	17,164	18,285	51
Smithfield	(1.26)	(917)	(2,713)	2,153
Windsor	(0.29)	(579)	(685)	2,362

TABLE 1 (CONTD)

RICHEL
COUNTIES, INDEPENDENT CITIES, TOWNS

	AREA[1] Sq.Miles 1969	POPULATION[2] 1960	1970	Persons per sq.mi. 1970
Nansemond County	427.70	31,366	35,166	82
Holland	(0.20)	(338)	(400)	2,000
Whaleyville	(0.63)	(402)	(332)	527
Southampton County	603.19	27,195	18,582	31
Boykins	(0.55)	(710)	(742)	1,349
Branchville	(0.25)	(158)	(189)	756
Capron	(0.39)	(327)	(314)	805
Courtland	(0.68)	(855)	(899)	1,322
Ivor	(1.02)	(398)	(444)	435
Newsoms	(0.49)	(423)	(389)	794
Chesapeake City*	377.02	73,647	89,580	238
Franklin City	3.81	7,366	6,880	1,806
Norfolk City	60.56	304,869	307,951	5,085
Portsmouth City	22.92	114,773	110,963	4,841
Suffolk City	2.30	12,609	9,858	4,286
Virginia Beach City+	310.50	85,218	172,106	554
Planning District Twenty-one				
Peninsula PDC		242,874	319,081	
James City County	182.30	11,539	17,853	98
York County	145.54	21,583	33,203	228
Poquoson	(15.60)	(4,278)	(5,441)	349
Hampton City	72.00	89,258	120,779	1,678
Newport News City	118.16	113,662	138,177	1,165
Williamsburg City	3.00	6,832	9,069	3,023
TOTAL	6834.28	1,513,179	1,797,053	
NET GAIN			283,874	

*Formerly City of South Norfolk & Norfolk County
+Formerly City of Virginia Beach & Princess Anne County
[1]County road maps, Virginia Dept, of Highways; county totals include town but not city areas
[2]See Appendix
[3]Incorporated town indented--figures included in county total
[4]Jarratt totals found under Sussex County

Source: Population Projections to 1980, 1990, 2000, & 2020, for Virginia Counties, Cities, & Planning Districts, Statistical Inf. Series, No. 71-1, issued March '71, Commonwealth of Va., Division of State Planning and Community Affairs.

TABLE II

Climatic Seasons

WINTER -- November 1 to March 28

A period of high storminess with the major polar frontal system far to the south in the Northern Hemisphere.
Subtropical anticyclones generally weak
Continental highs well developed
Circulation indices highly variable
A general in-flow of air from Canada
Usually only one Aleutian and one Icelandic Low

SPRING -- March 28 to June 25

A period of intermediate storminess with diminishing frontal intensity.
Subtropical anticyclones stronger
Cyclonic conditions prevail
Continental highs weaker and less persistent; tend to be replaced more frequently
Circulation indices show intermediate variability
Northern storm tracks more common in the U.S.
General out-flow into Canada
Double Aleutian Low, and later split of Icelandic Low reduce length of the "long" waves

SUMMER -- June 25 to August 21

A period of little storminess and weak fronts
Strong subtropical anticyclones
Little variability in circulation indices
Large scale synoptic patterns persistent
Continental anticyclones missing
Mean in-flow from Canada
Well developed "heat" low persists in the Southwest U.S.
Aleutain Low Missing, Icelandic Low broken into several weak centers

AUTUMN -- August 21 to November 1

A period of increasing storminess, with the polar front moving southward and intensifying
Generally anticyclonic conditions in middle latitudes
A single cell of the Aleutian Low located in Bering Sea and Gulf of Alaska area after a short period of two cells
A cell of the Azores high occupies Southeast U.S.
Geostrophic sea-level out-flow into Canada, but winter in-flow from Canada begins after September 20 with advent of higher zonal index and Indian Summer

Source: Bryson and Lahey, 1958

TABLE III

GEOGRAPHIC APPLICATIONS PROGRAM, USGS

LAND USE CLASSIFICATION SCHEME*

Level I	Level II
URBAN AND BUILT UP	Residential Commercial and Services Industrial Extractive Major Transport Routes and Areas Institutional Strip and Clustered Settlement Mixed Open and Other
AGRICULTURAL	Cropland and Pasture Orchards, Groves, Vineyards, Bush fruits, and Horticultural Areas Feeding Operations Other
FORESTLAND	Heavy Crown Cover (40% & over) Light Crown Cover (10% to 39%)
WATER	Streams and Waterways Lakes Reservoirs Bays and Estuaries Other
NON-FORESTED WETLAND	Vegetated Bare
BARREN LAND	Salt Flats Sand other than Beaches Bare Exposed Rock Beaches Other

* As applicable to RICHEL

TABLE IV

NON-INVENTORY AND INVENTORY ACREAGES (1,000 Acres)

State County	Total Land Area 1967	NON-INVENTORY ACREAGE: Federal Non-Cropland 1967	Federal Non-Cropland 67/58	Urban And Built-Up 1967	Urban And Built-Up 67/58	Small Water Areas 1967	Small Water Areas 67/58	Total Non-Inventory 1967	INVENTORY ACREAGE 1967
State	25,458.2	2,125.7	1.0	994.5	1.5	72.5	1.2	3,192.8	22,265.4
Charles City	117.1	0.0	0.0	1.3	1.4	0.4	0.8	1.7	115.9
Chesapeake	263.6	5.7	1.0	53.7	4.8	0.9	1.0	60.4	203.2
Chesterfield	299.3	3.3	1.9	54.9	1.7	1.5	1.3	59.7	239.5
Dinwiddie	329.6	15.0	1.0	10.0	2.9	0.4	1.3	25.4	304.1
Goochland	184.9	0.0	0.0	4.0	2.1	0.3	1.0	4.4	180.5
Greensville	192.6	0.0	0.0	3.9	1.1	0.6	1.2	4.6	188.0
Hampton	34.4	4.2	ND	30.8	1.0	0.0	0.0	35.0	2.3
Hanover	298.2	0.2	1.0	7.1	1.7	0.7	1.2	8.1	290.0
Henrico	172.1	0.4	1.0	53.6	2.3	0.2	1.0	54.3	117.7
Isle of Wight	204.1	0.2	2.0	2.9	1.1	0.6	1.2	3.7	200.3
James City	96.6	2.5	1.0	9.8	1.8	0.2	2.0	12.6	84.0
Nansemond	258.5	2.3	1.0	13.5	1.5	1.1	1.1	17.1	241.4
New Kent	134.7	0.0	0.0	2.0	1.3	0.1	1.0	2.1	132.5
Newport News	47.7	1.2	ND	43.0	1.1	0.0	0.0	44.2	2.7
Powhatan	171.5	0.0	0.0	3.5	4.4	0.5	1.0	4.1	167.4
Prince George	184.3	9.7	1.2	7.2	3.4	0.2	1.0	17.3	166.9
Southampton	388.4	0.0	0.0	4.7	1.0	1.7	1.0	6.4	382.0
Surry	179.2	0.0	0.0	2.7	1.4	0.6	1.0	3.4	175.7
Sussex	317.4	0.0	0.0	4.6	1.0	2.2	1.1	6.9	310.5
Virginia Beach	162.8	12.3	1.0	15.8	1.0	1.3	1.3	29.6	133.2
York	78.7	31.3	1.0	16.1	1.2	0.1	1.0	47.6	31.0
				345.1	1.6				

Source: Virginia Conservation Needs Inventory of 1967, published by Virginia Polytechnic Inst., Extension Division, Publication 384, February, 1970, Table I.

ND - Not defined, denominator zero.

TABLE V

1967 INVENTORIED LAND IN 1,000 ACRES WITH CHANGES SINCE 1958*

City & County	Total Land Area	Total Land Inventoried	Cropland 1967	Cropland 67/58	Pasture 1967	Pasture 67/58	Forest 1967	Forest 67/58	Other 1967	Other 67/58
Charles City	117.1	115.9	17.1	1.0	4.2	0.6	84.9	1.0	8.9	0.8
Chesapeake	263.6	203.2	63.3	1.4	5.6	0.5	120.3	0.8	13.8	1.0
Chesterfield	299.3	239.5	18.6	0.6	5.5	1.1	209.5	0.9	5.9	0.8
Dinwiddie	329.6	304.1	50.5	1.0	7.5	0.4	239.2	1.0	6.7	0.7
Goochland	184.6	180.5	38.0	1.5	25.0	0.9	114.1	0.9	3.3	0.4
Greensville	192.6	188.0	43.1	0.8	4.8	2.4	135.5	1.0	4.4	1.5
Hampton	34.4	2.3	0.3	0.5	0.2	2.0	0.5	0.2	1.3	0.8
Hanover	298.2	290.0	65.2	1.0	20.3	0.9	193.6	0.9	10.8	2.4
Henrico	172.1	117.7	22.8	1.0	6.0	0.7	78.6	0.9	10.3	0.6
Isle of Wight	204.1	200.3	66.4	1.0	5.8	1.1	118.9	0.9	9.1	0.9
James City	96.6	84.0	11.4	0.8	2.0	0.8	61.3	1.0	9.2	0.8
Nansemond	258.5	241.4	66.1	1.0	5.6	0.5	160.8	0.9	8.8	0.8
New Kent	134.7	132.5	11.3	0.7	2.9	1.5	107.9	1.0	10.3	1.0
Newport News	47.7	2.7	0.5	1.2	0.5	0.8	0.7	0.2	0.9	2.2
Powhatan	171.5	167.4	24.5	0.9	11.8	1.5	123.9	0.9	7.0	1.5
Prince George	184.3	166.9	37.4	0.8	3.3	1.3	126.5	0.9	4.6	2.4
Southampton	388.4	382.0	111.9	0.9	11.0	1.0	254.3	1.0	4.7	0.4
Surry	179.2	175.7	41.3	1.2	1.2	0.3	127.1	0.9	6.0	1.2
Sussex	317.4	310.5	53.4	1.0	8.8	0.8	240.3	0.9	7.9	1.5
Virginia Beach	162.8	133.2	64.9	1.9	4.0	0.5	50.0	0.8	14.2	1.5
York	78.7	31.0	2.3	0.6	0.8	1.3	22.4	1.0	5.4	0.6

*Taken from Virginia Conservation Needs Inventory of 1967 published by Virginia Polytechnic Institute Extension Division. Publication 384, February, 1970, Table II.

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TABLE VI

FOREST ACREAGE[2] (1,000 Acres) AND PERCENT COMMERCIAL FOREST TYPES[1]

County	1967 Acreage	[2]Change 67/58	Loblolly Pine	Oak Pine	Oak Hickory	Oak Gum Cypress	Elm Ash Cottonwood	Short Leaf Pine	Virginia Pine	[1]% Non Coml.
Charles City	84.9	1.0	34.8	16.6	45.6	2.9	-	-	-	-
Chesterfield	209.5	0.9	21.7	19.6	54.6	3.4	-	-	-	0.9
Dinwiddie	239.2	1.0	35.9	29.5	34.6	-	-	-	-	-
Goochland*	114.1	0.9	2.9	19.8	42.4	2.9	-	2.9	29.0	-
Greensville	135.5	1.0	24.0	21.2	49.5	2.0	3.0	-	-	-
Hanover	193.6	0.9	13.7	25.5	46.9	-	1.3	-	12.3	0.1
Henrico	78.6	0.9	19.7	11.0	64.5	-	-	0.3	-	0.5
Isle of Wight	118.9	0.9	30.2	15.4	48.2	6.3	-	-	-	-
James City	61.3	1.0	15.1	6.0	63.6	12.1	-	-	3.0	27.4
Nansemond	160.8	0.9	17.8	9.0	39.0	32.1	1.8	-	-	-
New Kent	107.9	1.0	25.9	16.0	54.6	-	-	-	3.1	-
Powhatan	123.9	0.9	6.4	12.5	52.7	-	6.2	5.2	16.5	-
Prince George	126.5	0.9	49.9	5.8	45.8	2.9	-	2.9	-	3.9
Southampton	254.3	1.0	24.2	20.5	34.3	20.7	-	-	-	-
Surry	127.1	0.9	36.2	19.4	27.0	12.8	-	2.3	2.1	-
Sussex	240.3	0.9	28.3	24.0	43.5	4.0	-	-	-	-
York	22.4	1.0	29.4	12.9	57.6	-	-	-	-	8.0
TOTAL			24.6	18.7	44.5	6.8	0.7	0.8	3.3	

*Type not common to other areas, 2.0% Red Cedar
[1]Virginia Division of Forestry; Forest Survey of 1966
[2]Virginia Conservation Needs Inventory of 1967, Virginia Polytechnic Institute, Bulletin 384, 1970.

TABLE VII

1970 CROP ACREAGES

County Or City	Tobacco	Winter Wheat	Barley	Corn	All Hay	Soybean	Cotton	Peanuts
Charles City	-	2,700	1,850	4,700	1,200	4,100	-	-
Chesterfield	235	450	400	2,600	3,700	1,900	-	25
Dinwiddie	2,156	2,150	900	9,500	3,750	7,600	5	3,750
Goochland	110	2,400	1,250	3,000	11,400	500	-	-
Greensville	600	200	350	8,800	1,900	5,600	2,620	9,700
Hanover	90	4,250	2,100	12,000	11,900	15,700	-	-
Henrico	-	1,300	1,250	2,600	3,900	3,700	-	-
Isle of Wight	3	500	450	18,600	2,700	8,800	10	16,100
James City	-	450	800	1,900	900	3,000	-	90
Nansemond	94	1,800	250	15,700	2,650	13,900	160	14,600
New Kent	-	1,700	800	4,200	950	3,500	-	-
Powhatan	92	700	950	3,900	5,850	500	-	-
Prince George	57	1,100	530	5,600	2,050	7,000	5	3,350
Southampton	50	850	170	27,000	5,600	11,600	1,270	31,000
Surry	-	400	350	8,300	1,500	6,800	170	8,550
Sussex	340	750	530	10,000	2,400	9,400	-	14,300
York	-	100	100	900	650	900	-	-
Chesapeake	-	3,550	270	13,500	1,500	27,500	-	-
Virginia Beach	-	5,350	1,450	9,000	950	28,200	-	-

Source: Virginia Department of Agriculture & Commerce
Crop Reporting Service
203 North Governor Stree
Richmond, Virginia 23219

TABLE VIII

CHANGES IN FARM CHARACTERISTICS 1959 - 1964

	No. Of Farms		Area in Farms			% of Area in Farms		Average Farm Size in Acres	
	1959	1964	1959	1964	64/59	1959	1964	1959	1964
Charles City	171	107	43,828	37,773	0.9	37.2	32.1	253.2	353.0
Chesterfield	533	417	70,953	56,840	0.8	23.7	19.0	133.1	136.3
Dinwiddie	1,259	956	158,852	137,734	0.9	48.2	41.8	126.2	144.1
Goochland	558	472	88,120	94,508	1.1	47.6	51.1	157.9	200.2
Greensville	735	613	101,480	87,139	0.8	52.7	45.2	138.1	142.2
Hanover	1,074	879	154,109	145,164	0.9	51.7	48.7	143.5	165.1
Henrico	518	337	64,624	49,526	0.7	37.5	28.8	124.8	147.0
Isle of Wight	686	532	106,409	100,274	0.9	52.1	49.1	155.1	188.5
James City	155	96	30,522	25,675	0.8	31.6	26.6	196.9	267.4
Nansemond	998	784	121,379	117,826	0.9	46.9	45.6	121.6	150.3
New Kent	196	147	43,149	34,017	0.7	31.8	25.1	220.1	231.4
Powhatan	396	304	80,152	65,253	0.8	46.7	38.0	202.4	214.6
Prince George	445	401	78,734	75,257	0.9	42.7	40.8	176.9	187.7
Southampton	1,269	988	260,790	22,631	0.8	67.1	58.6	205.5	229.1
Surry	538	396	78,554	70,373	0.8	43.8	39.3	146.0	177.7
Sussex	787	580	134,552	126,972	0.9	42.4	40.0	171.0	218.9
York	202	130	15,185	9,870	0.6	9.3	6.0	75.2	75.6
Chesapeake	501	474	75,775	78,286	1.0	28.7	29.7	151.2	165.1
Virginia Beach	417	394	60,383	62,998	1.0	37.0	38.6	144.8	159.9

Source: U.S. Bureau of Census 1959, 1964, Census of Agriculture, Virginia, Volume 1, Part 24.

TABLE IX

FLOW OF JAMES RIVER COMBINED WITH THE JAMES RIVER
& KANAWHA CANAL AT RICHMOND, VIRGINIA
MEAN MONTHLY DISCHARGE IN CUBIC FEET PER SECOND

Size of Drainage Area: 6757 sq. miles
Average Discharge Over 35 Years: 7127 cfs.

Month	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	10-Year Average
January	5757	7746	3297	11999	10242	10982	8960	1587	9093	9453	7912
February	4103	16446	14172	9803	5777	12166	14152	11114	7040	8058	10283
March	6587	12306	11986	24750	24647	12581	14166	8563	18961	11053	12850
April	13640	20273	15154	15529	5159	7366	8992	3591	4741	5123	9957
May	4746	11497	10589	6896	3616	4469	5313	7682	7195	5552	6756
June	6853	6300	5635	6697	2773	1684	2402	2261	3169	4083	4186
July	2406	2363	3112	4357	1306	1363	1680	695	1925	1880	2109
August	2723	2560	3165	2736	933	858	1163	812	5383	1584	2192
September	2344	3877	2956	1890	826	909	1022	3026	1994	926	1977
October	9551	2096	11419	1940	912	1768	1686	7074	3091	2365	4190
November	5685	2055	5640	6140	1870	2273	1266	3663	2435	4295	3532
December	8594	2178	14823	3850	3027	5174	1193	5390	1108	2829	4817

FLOW OF THE APPOMATTOX RIVER NEAR PETERSBURG, VIRGINIA
MEAN MONTHLY DISCHARGE IN CUBIC FEET PER SECOND

Size of Drainage Area: 1335 sq. miles
Average Discharge Over 39 Years: 1165 cfs.

Month	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	10-Year Average
January	590	898	2360	1855	1133	924	3444	1547	1641	904	1530
February	1771	2884	2251	1042	3208	3329	2721	1538	2238	1993	2298
March	1383	1950	2689	900	2129	2024	3358	3193	1336	2210	2117
April	1529	1589	2896	2267	2282	1974	2973	744	952	1197	1840
May	619	405	2689	637	1639	1860	1096	558	476	551	1053
June	816	827	983	428	625	1951	1297	480	253	338	800
July	377	158	472	617	248	804	1241	198	346	391	485
August	434	256	1033	344	395	854	444	104	228	159	425
September	265	777	331	169	1008	625	381	100	257	206	412
October	551	503	479	581	419	1729	317	112	450	242	539
November	1087	1658	511	1307	405	657	1217	370	381	195	779
December	1004	2920	1085	1150	614	2831	785	545	745	201	1188

TABLE XI

FLOW OF THE CHICKAHOMINY NEAR PROVIDENCE FORGE, VIRGINIA

MEAN MONTHLY DISCHARGE IN CUBIC FEET PER SECOND

Size of Drainage Area: 249 sq. miles

Average Discharge Over 27 Years: 253 cfs.

Month	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	10-Year Average
January	474	334	351	803	349	375	305	61	156	391	360
February	262	635	845	510	324	513	370	295	331	131	422
March	200	584	639	885	730	406	438	221	361	391	486
April	561	568	461	695	168	311	293	113	132	161	346
Ma-	136	195	421	186	98	134	103	161	167	89	168
June	82	64	608	220	429	37	76	72	33	100	172
July	625	103	268	168	29	55	92	35	24	13	141
August	288	618	76	68	17	95	24	30	119	29	136
September	89	510	52	45	24	157	30	64	38	7	102
October	154	189	407	42	19	162	19	187	19	4	120
November	562	198	144	265	87	97	18	80	36	57	154
December	388	244	623	157	203	175	28	120	240	66	224

TABLE XII

MAJOR WATERWORKS SYSTEMS*

mgd - millions of gallons a day
gpm - gallons per minute
gpd - gallons per day

	Ownership	Estimated Daily Use	Capacity	Flouridation	Remarks
Charles City County					
None					
Chesterfield County					
Falling Creek	Chesterfield County	1.68 mgd	3.0 mgd	yes	
Swift Creek	Chesterfield County	2.65 mgd	5.0 mgd	yes	
Appomattox River Water Authority	Colonial Heights, Petersburg, Chesterfield County, Dinwiddie County, & Prince George County	9.0 mgd	24.0 mgd	yes	
Dinwiddie County					
Town of McKenny	Public	30,000 gpd	90 gpm	no	Wells
Appomattox River Water Authority					See Chesterfield County
Goochland County					
Goochland Courthouse	Private	-	40 gpm	no	Wells
Crozier	Private	-	10 gpm	no	Wells
Greenland County					
Emporia	Public	1.0 mgd	4 mgd	no	
Jarratt	Public	90,000 gpd	155,000 gpd	no	
Hanover County					
Mechanicsville Sanitary District	Public	30,000 gpd	-	no	
Ashland	Public	0.35 mgd	1.0 mgd	no	

*Source: Virginia Health Data Book, Office Comprehensive Health Planning, Virginia State Dept. of Health, Richmond, Virginia, March, 1971.

TABLE XII (CONT'D)

MAJOR WATERWORKS SYSTEMS

	Ownership	Estimated Daily Use	Capacity	Flouri-dation	Remarks
Henrico County					
Sandston	Henrico County	-	1.2 mgd	no	Wells
Highland Springs	Henrico County	-	1.5 mgd	no	Wells
Glenwood Farms	City of Richmond	600,000 gpd	-	-	Partially from City of Richmond, partially from wells
Winsor Place	Henrico County	-	140,000 gpd	no	Wells
Lawndale Farms	Henrico County		330 gpm	no	Wells
Isle of Wight					
Smithfield	Public	0.24 mgd	400 gpm	no	Wells
Battery Park	Private	30,000 gpd	465 gpm	no	Wells
Carrsville	Private	40,000 gpd	50 gpm	no	Wells
Carrollton	Public&Private	17,000 gpd	100 gpm	no	Wells
Rescue	Private	20,000 gpd	40 gpm	no	Wells
Rushmore	Private	24,000 gpd	30 gpm	no	Wells
Winsor	Private	90,000 gpd	500 gpm	no	Wells
Zuni	Private	7,000 gpd	11 gpm	no	Wells
James City County					
Williamsburg	Public	2.26 mgd	2.5 mgd	no	-
Toano	Private	30,000 gpd	72 gpm	no	Wells
Jamestown Foundation	State of Virginia	10,000 gpd	175 gpm	no	Wells
Nansemond County					
Whaleyville	Public	35,000 gpd	140 gpm	no	Wells
Nolland	Private	30,000 gpd	215 gpm	no	Wells
Chuckatuck	Private	-	225 gpm	no	Wells
Crittenden	Public	-	50 gpm	no	Wells
Elipse	Public&Private	35,000 gpd	125 gpm	no	Wells

TABLE XII (CONT'D)

MAJOR WATERWORKS SYSTEMS

	Ownership	Estimated Daily Use	Capacity	Flouri-dation	Remarks
New Kent County					
A lake front development	Public	-	175 gpm	no	Wells
Powhatan County					
Powhatan	Public	-	-	no	Wells
Prince George County					
Old Dominion Water Co.	Private	26to29 mgd	32 mgd	yes	Approx. 3mgd to domestic accounts, the remainder to industrial account.
Southampton County					
Capron	Public	31,000 gpd	80 gpm	no	Wells
Courtland	Public	110,000 gpd	315 gpm	no	Wells
Boykins	Public	110,000 gpd	390 gpm	no	Wells
Ivor	Public	50,000 gpd	170 gpm	no	Wells
Franklin	Public	850,000 gpd	2,065 gpm	no	Wells
Newsoms	Public	20,000 gpd	75 gpm	no	Wells
Sodley	Public	-	150 gpm	no	Wells
Surry County					
Claremont	Private	50,000 gpd	100,000 gpd	no	Wells
Surry	Private	30,000 gpd	50 gpm	no	Wells
Sussex County					
Jarret	-	-	-	-	Jarret is divided by county line; see Greensville County
Stony Creek	Public	35,000 gpd	43,000 gpd	no	Wells
Wakefield	Public	150,000 gpd	300 gpm	no	Wells
Waverly	Public	150,000 gpd	550 gpm	no	Wells
Sussex	County owned	1,000 gpd	25 gpm	no	Wells

TABLE XII (CONT'D)
MAJOR WATERWORKS SYSTEMS

	Ownership	Estimated Daily Use	Capacity	Flouri-dation	Remarks
York County	-	-	-	-	Most of York County is supplie by the Newport News system
Large Municipalities					
City of Chesapeake	-	-	-	-	Approx. 4.6mgd are supplied by Norfolk and Portsmouth
City of Hampton	-	-	-	-	Water is supplied by Newport News
City of Newport News	Public	30to32 mgd	36 mgd	yes	Has three plants which supply Newport News, Hampton, and most of York County
City of Norfolk	Public	63 mgd	79 mgd	yes	
City of Petersburg	-	-	-	-	Approx. 5.5mgd is supplied by the Appomattox RiverWater Authority
City of Portsmouth	Public	17.3 mgd	31 mgd	yes	
City of Richmond	Public	30to50 mgd	80 mgd	yes	
City of Virginia Beach	-	-	-	-	Supplied by City of Norfolk system

SUITABILITY OF UNTREATED GROUND WATER FOR PUBLIC SUPPLY

TABLE XIII

Number of determinations	Chemical characteristics	Range in concentrations (ppm) Min.	Avg.	Max.	Maximum acceptance concentrations U.S.P.H.S. standards (ppm)[10]
	Basement rocks				
11	Hardness	11	85	285	
8	Iron	.03	.8	[2]5.1	0.3
11	Bicarbonate	18	145	309	
11	Sulfate	.2	66	[2]468	250
11	Chloride	2.6	34	63	250
6	Nitrate	.1	1.14	5.4	45
8	Fluoride	.1	2.3	[2]5.8	[9]1.2
	Cretaceous aquifers (Patapsco and Patuxent)				
32	Hardness	4.1	55	225	
24	Iron	.02	.82	[6]8.9	0.3
34	Bicarbonate	12	251	775	
34	Sulfate	1	12	44	250
34	Chloride	1	33	[2]351	250
20	Nitrate	.05	.65	2.5	45
21	Fluoride	.0	2.4	[7]6.6	[9]1.2
	Upper Cretaceous to Paleocene				
24	Hardness	3	24.1	76	
15	Iron	.02	1.68	[4]16	0.3
25	Bicarbonate	136	386	686	
25	Sulfate	1.6	47	[1]265	250
25	Chloride	1	475	[8]4,978	250
12	Nitrate	.1	4.4	82	45
18	Fluoride	.1	1.7	[8]3.1	[9]1.2
	Paleocene to Eocene				
9	Hardness	12	76	152	
8	Iron	.03	2.7	[4]15	0.3
10	Bicarbonate	153	194	260	
10	Sulfate	6.7	19	75	250
10	Chloride	1	12	69	250
5	Nitrate	.3	.5	.7	45
9	Fluoride	.1	.6	[1]1.9	[9]1.2
	Eocene-Nanjemoy				
14	Hardness	10	51	100	
6	Iron	.06	.3	[2].93	0.3
14	Bicarbonate	131	253	402	
14	Sulfate	5	25	247	250
14	Chloride	2	20	149	250
4	Nitrate	.2	.4	.6	45
11	Fluoride	.2	.8	[3]2.0	[9]1.2
	Eocene-Chickahominy				
9	Hardness	6	62	240	
4	Iron	.06	4.56	[1]18	0.3
9	Bicarbonate	233	494	11.84	
9	Sulfate	1	56	[1]300	250
9	Chloride	2	413	[1]2,200	250
5	Nitrate	.39	.65	1.0	45
8	Fluoride	.9	1.6	[3]4.6	[9]1.2
	Miocene-Chesapeake Group				
19	Hardness	3	118	576	
11	Iron	.04	4.6	[7]19	0.3
19	Bicarbonate	5	171	625	
19	Sulfate	1	18	105	250
19	Chloride	1	66	[1]950	250
16	Nitrate	.1	3.5	38	45
13	Fluoride	3.2	.7	[2]3.4	[9]1.2

[1] One analysis exceeded acceptable concentrations.
[2] Two analyses exceeded acceptable concentrations.
[3] Three analyses exceeded acceptable concentrations.
[4] Four analyses exceeded acceptable concentrations.
[5] Five analyses exceeded acceptable concentrations.
[6] Six analyses exceeded acceptable concentrations.
[7] Nine analyses exceeded acceptable concentrations.
[8] Twelve analyses exceeded acceptable concentrations.
[9] Annual mean daily maximum temperature at Williamsburg, Va. was 69.2°F for 64 years of record.
[10] Standards are for treated water-raw water can frequently be treated to comparable quality.

Source: D. DeBuchananne (1968)

STRATIGRAPHY OF THE COASTAL PLAIN AQUIFER IN RICHEL

TABLE XIV

System	Series	Formation		Approximate thickness (feet) outcrop	Approximate thickness (feet) subsurface	Physical character	Hydrologic comments
Quaternary	Recent and Pleistocene			0 – 100	0	Unconsolidated gravels, sand, loam, partly of fluvial and partly of marine origin.	Good aquifers for domestic and small industrial supplies when sources are located some distance from surface saline waters.
Tertiary	Miocene	Chesapeake Group	Yorktown St. Marys Choptank Calvert	125 180 50 200	0 to 600+	Blue and gray sandy diatomaceous shales, shell marls, and minor amounts of sand.	In eastern peninsular area sands yield moderate supplies subject to salt-water encroachment when pumping is heavy near marine estuaries.
	Eocene	Chickahominy (subsurface)		–	0 to 1,000	Blue, gray, and brown pyritic and glauconitic clay.	Aquiclude
		Pamunkey Group	Nanjemoy	125		Gray marls and fine quartz and glauconitic sands.	Quartz and glauconitic sands furnish water to some screened wells.
	Paleocene		Aquia	100			
Cretaceous	Upper Cretaceous	Mattaponi (subsurface)		–	0 to 100+	Mottled clay, glauconitic sands and marls with thick quartz basal sand.	A very good water-bearing formation in central part of Coastal Plain. East of Williamsburg the formation yields brackish water.
		Potomac Group[1]	Patapsco	150	Up to 4,500		
	Lower Cretaceous		Patuxent	250–300		Lenticular sands and clays underlying the entire Coastal Plain of Virginia.	Some of the sands are excellent aquifers and furnish large supplies to wells. Down dip to the east these same deposits contain water too brackish for use.
Pre-Cretaceous		Basement complex				Large thick crystalline masses of granites, gneiss, schist and other metamorphic type rocks	Good aquifers where overlain by permeable soils adjacent to the Fall Line, down dip water quality becomes poor.

[1] Not recognized in outcrop

Source: D. DeBuchananne (1968)

TABLE XV

HOUSING CHARACTERISTICS, 1970

	Charles City	Chester-field	Din-widdie	Gooch-land	Greens-ville	Hanover	Henrico
All housing units	1,578	22,984	6,198	2,867	2,814	10,947	49,527
All year-round housing units	1,570	22,494	6.189	2,870	2,810	10,934	49,520
Pop. per occupied unit	4.2	3.4	3.5	3.6	3.7	3.4	3.2
% owner occupied	79.8	73.8	62.3	70.9	60.8	78.3	69.5
% renter occupied	13.5	23.1	30.4	19.2	31.1	17.6	28.0
Median rooms	5.2	5.7	5.1	5.4	4.9	5.7	5.6
% units in structure							
1 unit	91.7	82.0	79.9	90.3	93.8	91.9	83.0
2 or more units	1.5	12.6	15.4	3.4	1.8	4.2	16.7
mobile home or trailer	6.8	5.4	4.7	6.3	4.4	3.9	0.2
% plumbing facilities	51.1	94.4	74.6	65.7	54.1	75.6	97.5
All occupied units	1,472	21,793	5,744	2,593	2,588	10,500	48,250
Persons/room							
% 1.00 or less	76.2	94.6	86.1	84.9	82.0	91.7	96.1
% 1.01 - 1.50	16.0	4.2	8.7	10.5	10.8	6.0	3.3
% 1.51 or more	7.8	1.2	5.6	4.6	7.2	2.2	0.6
Median value ($)	7,200	20,800	14,100	12,100	9,900	18,500	18,200
Median contract rent ($ rounded)	40	99	77	58	40	65	112
% no-cash rent	5.0	1.5	2.4	3.8	4.1	2.5	0.9

TABLE XV (CONT'D)

HOUSING CHARACTERISTICS, 1970

	Isle of Wight	James City	Nanse-mond	New Kent	Pow-hatan	Prince George	So'hamp-ton	Surry	Sussex	York
All housing units	5,432	5,030	10,275	1,632	1,971	5,902	5,442	2,041	3,263	9,257
All year-round housing units	5,396	4,974	10,260	1,591	1,950	5,898	5,439	1,906	3,261	9,232
Pop. per occupied unit	3.6	3.4	3.6	3.5	3.6	3.6	3.6	3.7	3.8	3.6
% owner occupied	61.1	64.1	61.9	75.3	68.9	57.6	52.5	56.2	58.9	68.7
% renter occupied	31.7	27.7	33.8	17.8	14.7	31.4	38.0	26.6	34.3	27.7
Median rooms	5.3	5.0	5.3	5.1	5.4	5.1	5.3	5.5	5.3	5.6
% units in structure										
1 unit	86.0	72.3	92.5	88.7	91.3	62.3	94.0	91.6	92.8	81.6
2 or more units	6.8	13.6	4.8	2.7	3.0	20.8	3.7	3.2	3.5	13.5
mobile home or trailer	7.1	13.9	2.7	8.5	5.7	16.5	2.3	5.2	3.7	4.9
% plumbing facilities	75.6	83.1	63.9	73.5	73.5	88.5	57.1	59.4	57.0	92.3
All occupied units	5,008	4,572	9,817	1,482	1,757	5,718	4,929	1,580	3,042	8,900
Persons/room										
% 1.00 or less	85.2	87.7	86.0	85.4	87.0	88.9	84.2	82.6	79.4	91.9
% 1.01 - 1.50	9.4	7.7	9.1	10.5	8.9	7.2	9.0	10.8	11.2	6.5
% 1.51 or more	5.3	4.6	5.0	4.1	4.0	3.8	6.8	6.5	7.9	1.6
Median value ($)	12,400	17,900	12,600	11,700	12,000	17,700	11,800	8,600	9,600	19,600
Median contract rent ($rounded)	45	97	49	55	48	107	40	40	40	91
% no-cash rent	4.4	4.0	4.6	4.0	4.0	16.9	6.5	5.4	6.2	11.4

TABLE XV (CONT'D)

HOUSING CHARACTERISTICS, 1970

	Chesa-peake	Colonial Heights	Emporia	Franklin	Hampton	Hopewell	Newport News
All housing units	25,865	4,892	1,814	2,206	36,556	7,642	41,696
All year-round housing units	25,859	4,890	1,811	2,204	36,470	7,642	41,694
Pop. per occupied unit	3.5	3.2	3.0	3.2	3.3	3.2	3.2
% owner occupied	70.0	69.8	46.0	48.5	60.0	58.0	52.5
% renter occupied	27.2	26.9	49.6	47.3	34.8	36.8	42.4
Median rooms	5.4	5.6	5.1	5.2	5.3	5.2	5.2
% units in structure							
1 unit	84.3	87.1	86.9	73.0	78.3	77.5	66.8
2 or more units	12.0	12.8	12.0	26.9	20.1	20.4	29.9
mobile home or trailer	3.7	0.1	01.0	0.0	1.5	2.0	3.4
% plumbing facilities	93.3	99.0	76.0	88.6	98.0	94.4	98.1
All occupied units	25,151	4,730	1,733	2,111	34,586	7,242	39,541
Persons/room							
% 1.00 or less	90.8	96.2	88.5	88.8	93.0	92.7	92.4
% 1.01 - 1.50	7.0	3.4	7.0	7.5	5.8	5.7	6.0
% 1.51 or more	2.1	0.3	4.5	3.7	1.2	1.6	1.6
Median value ($)	15,800	17, 000	13,200	14,600	16,900	14,000	18,900
Median contract rent ($ rounded)	72	96	46	52	100	81	83
% no-cash rent	2.1	2.1	3.6	2.6	2.2	1.2	3.3

TABLE XV (CONT'D)

HOUSING CHARACTERISTICS, 1970

	Norfolk	Petersburg City	Portsmouth	Richmond	Suffolk	Virginia Beach	Williamsburg
All housing units	91,065	11,966	36,475	87,083	3,609	47,960	2,613
All year-round housing units	91,004	11,966	36,472	87,068	3,609	47,396	2,612
Pop. per occupied unit	3.0	3.2	3.2	2.9	2.9	3.5	2.5
% owner occupied	40.8	47.3	52.3	46.6	40.6	65.1	32.5
% renter occupied	54.4	46.7	42.3	48.4	52.1	30.1	59.4
Median rooms	4.9	4.9	5.0	4.9	5.3	5.9	4.5
% units in structure							
1 unit	54.9	70.9	70.2	60.8	63.4	78.6	51.1
2 or more units	44.0	29.0	29.4	38.4	36.6	18.0	48.0
mobile home or trailer	1.0	0.1	0.4	0.7	0.0	3.4	0.8
% plumbing facilities	97.9	85.4	96.0	96.1	85.5	96.1	94.6
All occupied units	86,746	11,248	34,517	82,769	3,347	45,133	2,401
Persons/room							
% 1.00 or less	91.7	87.4	90.7	92.3	91.6	94.4	95.5
% 1.01 - 1.50	6.1	8.2	7.1	5.9	5.2	4.5	2.6
% 1.51 or more	2.0	4.3	2.2	1.8	2.8	1.2	1.9
Median value ($)	15,800	13,300	13,700	15,500	13,000	21,400	26,600
Median contract rent ($ rounded)	83	59	62	78	55	127	114
% no-cash rent	3.3	1.7	2.3	0.9	1.8	2.8	2.7

TABLE XVI

HOUSING RATE OF CHANGE AND DENSITY

Counties	1960[1] Housing Units	1970[2] Units	1970/1960	1970 Units per sq. mi.
* Charles City	1,270	1,578	1.24	7.74
* Chesterfield	19,931	22,498	1.13	48.02
* Dinwiddie	4,646	6,198	1.33	12.24
Goochland	2,314	2,876	1.24	9.75
Greensville	4,296	2,814	0.60	9.32
* Hanover	7,728	10,947	1.42	23.24
* Henrico	34,722	49,527	1.43	211.29
Isle of Wight	4,755	5,432	1.14	15.90
* James City	2,981	5,030	1.69	27.59
Nansemond	8,648	10,275	1.19	24.02
* New Kent	1,288	1,632	1.27	7.39
Powhatan	1.682	1.971	1.17	7.25
* Prince George	4,224	5,902	1.40	19.79
Southampton	5,431	5,442	1.00	9.02
Surry	1,934	2,041	1.06	6.67
Sussex	3,234	3,263	1.01	6.58
* York	6,333	9,257	1.46	63.61
Independent Cities				
* Chesapeake	21,088	25,865	1.23	68.60
* Colonial Heights	3,142	4,892	1.56	600.25
Emporia	1,752	1,814	1.04	759.00
Franklin	2,098	2,206	1.05	579.00
* Hampton	26,193	36,556	1.40	507.72
* Hopewell	5,390	7,642	1.42	676.28
* Newport News	31,946	41,696	1.31	352.88
* Norfolk	87,560	91,065	1.04	1503.72
* Petersburg	11,769	11,966	1.02	1334.00
* Portsmouth	33,349	36,475	1.09	1591.41
* Richmond	69,105	87,083	1.26	2180.89
Suffolk	4,112	3,609	0.88	1569.13
* Virginia Beach	24,879	47,960	1.93	154.46
* Williamsburg	1,566	2,613	1.67	871.00
Total	439,366	548,125		80.20
Net Gain	108,759 (24.75%)			

Net Population Gain/Net Housing Gain = 2.61

[1]U.S. Dept. of Commerce, Bureau of Census, County and City Data Book, 1967, Washington, D. C., 1968.

[2]U.S. Dept. of Commerce, Bureau of Census, Census of Housing, HC (1)-A48, 1971.

*Urban Corridor

TABLE XVII

SURFACE AREA IN HIGHWAY SYSTEM PAVING (In Acres)

County Or Municipality	Interstate[1]	Primary[2]	Secondary[3]	Urban Extended[4]	Other Streets[5]
Charles City	-	108.15	332.58		
Chesterfield	92.23	328.89	1,709.55		
Dinwiddie	207.12	280.89	1,256.33		
Goochland	217.13	231.61	665.98		
Greensville	97.75	76.91	607.21		
Hanover	114.73	294.07	1,418.15		
Henrico	226.83	299.33	2,006.18		
Isle of Wight	-	230.73	998.69		
James City	44.21	165.44	387.66		
Nansemond	-	326.47	1,058.06		
New Kent	155.14	165.69	435.36		
Powhatan	-	155.91	510.95		
Prince George	70.98	233.23	655.95		
Southampton	-	264.32	1,614.54		
Surry	-	151.86	596.82		
Sussex	-	269.61	1,077.43		
York	55.23	165.44	353.18		
Chesapeake	120.54			496.53	1,294.48
Colonial Hts.	27.69			16.14	154.41
Emporia	6.59			16.67	61.61
Franklin				23.75	78.72
Hampton	105.03			241.74	819.08
Hopewell				46.10	257.92
Newport News	91.46			286.40	869.81
Norfolk	140.63			372.26	1,802.06
Petersburg	36.92			496.53	1,294.48
Poquoson				43.39	75.46
Portsmouth	40.80			135.46	965.41
Richmond	112.94			311.41	2,020.97
Suffolk				27.83	81.16
Virginia Beach	22.73			293.72	2,111.64
Williamsburg				57.21	69.93
TOTAL	1,986.67	3,748.55	15,774.62	2,507.76	11,417.80

GRAND TOTAL of Surface Area In Highway System Paving In RICHEL: 43,571.41

[1] 7.757 acres/mi. 64 ft. wide
[2] 3.115 acres/mi. 25.7 ft. average width
[3] 2.424 acres/mi. 20 ft. wide
[4] 4.848 acres/mi. 40 ft. wide
[5] 2.909 acres/mi. 24 ft. wide

TABLE XVIII

HYDROLOGIC EFFECTS DURING A SELECTED SEQUENCE OF CHANGES IN LAND AND WATER USE ASSOCIATED WITH URBANIZATION*

Change in land or water use	*Possible hydrologic effect*
Transition from preurban to early-urban stage:	
Removal of trees or vegetation	Decrease in transpiration and increase in storm flow. Increased sedimentation of streams.
Construction of scattered city-type houses and limited water and sewage facilities	
Drilling of wells	Some lowering of water table.
Construction of septic tanks and sanitary drains	Some increase in soil moisture and perhaps a rise in water table. Perhaps some waterlogging of land and contamination of nearby wells or streams from overloaded sanitary drain system.
Transition from early-urban to middle-urban stage:	
Bulldozing of land for mass housing, some topsoil removed, farm ponds filled in	Accelerated land erosion and stream sedimentation and aggradation. Increased flood flows. Elimination of smallest streams.
Mass construction of houses, paving of streets, building of culverts	Decreased infiltration, resulting in increased flood flows and lowered groundwater levels. Occasional flooding at channel constrictions (culverts) on remaining small streams. Occasional overtopping or undermining of banks of artificial channels on small streams.
Discontinued use and abandonment of some shallow wells	Rise in water table.
Diversion of nearby streams for public water supply	Decrease in runoff between points of diversion and disposal.
Untreated or inadequately treated sewage discharged into streams or disposal wells	Pollution of stream or wells. Death of fish and other aquatic life. Inferior quality of water available for supply and recreation at downstream populated areas.
Transition from middle-urban to late-urban stage:	
Urbanization of area completed by addition of more houses and streets and of public, commercial, and industrial buildings	Reduced infiltration and lowered water table. Streets and gutters act as storm drains, creating higher flood peaks and lower base flow of local streams.
Larger quantities of untreated waste discharged into local streams	Increased pollution of streams and concurrent increased loss of aquatic life. Additional degradation of water available to downstream users.
Abandonment of remaining shallow wells because of pollution	Rise in water table.
Increase in population requires establishment of new water-supply and distribution systems, construction of distant reservoirs diverting water from upstream sources within or outside basin	Increase in local streamflow if supply is from outside basin.
Channels of streams restricted at least in part to artificial channels and tunnels	Increased flood damage (higher stage for a given flow). Changes in channel geometry and sediment load. Aggradation.
Construction of sanitary drainage system and treatment plant for sewage	Removal of additional water from the area, further reducing infiltration and recharge of aquifer.
Improvement of storm drainage system	A definite effect is alleviation or elimination of flooding of basements, streets, and yards, with consequent reduction in damages, particularly with respect to frequency of flooding.†
Drilling of deeper, large-capacity industrial wells	Lowered water-pressure surface of artesian aquifer; perhaps some local overdrafts (withdrawal from storage) and land subsidence. Overdraft of aquifer may result in salt-water encroachment in coastal areas and in pollution or contamination by inferior or brackish waters.
Increased use of water for air conditioning	Overloading of sewers and other drainage facilities. Possibly some recharge to water table, due to leakage of disposal lines.
Drilling of recharge wells	Raising of water-pressure surface.
Waste-water reclamation and utilization	Recharge to groundwater aquifers. More efficient use of water resources.

Source: Jens and McPherson, 1964

TABLE XIX

ESTIMATED SOIL LOSS FOR LAND-USE CATEGORIES IN RICHEL
(1,000 tons per acre per year)

	Urban	Cropland	Pasture	Forest	Other	Total
Charles City	7.5	32.8	3.6	23.8	99.7	167.4
Chesterfield	317.3	35.7	4.7	58.7	66.1	482.5
Dinwiddie	57.8	97.0	6.4	67.0	75.0	303.2
Goochland	23.1	73.0	21.3	32.0	37.0	186.4
Greensville	22.5	82.8	4.1	37.9	49.3	196.6
Hanover	41.0	125.2	17.3	54.2	121.0	358.7
Henrico	309.8	43.8	5.1	22.0	115.4	496.1
Isle of Wight	16.8	127.5	4.9	33.3	101.9	284.4
James City	56.6	21.9	1.7	17.2	103.0	200.4
Nansemond	78.0	126.9	4.8	45.0	98.6	353.3
New Kent	11.6	21.7	2.5	30.2	115.4	181.4
Powhatan	20.2	47.0	10.0	34.7	78.4	190.3
Prince George	41.6	71.8	2.8	35.4	51.5	203.1
Southampton	27.2	214.9	9.4	71.2	52.6	375.3
Surry	15.6	79.3	1.0	35.6	67.2	198.7
Sussex	26.6	102.5	7.5	67.3	88.5	292.4
York	93.1	4.4	.7	6.3	60.5	165.0
Chesapeake	345.1	121.6	4.8	33.7	154.6	659.8
Virginia Beach	162.4	124.6	3.4	14.0	159.0	463.4
Other Urban	1,309.3	-	-	-	-	1,309.3
TOTAL	2,983.1	1,554.4	116.0	719.5	1,694.7	7,067.7
Adj. Total		2,366.5*	191.3*			8,055.3*
Percentage	37.1	30.6*	2.4*	8.9	21.0	100.0

*Adjusted for poor conservation (See Text)

TABLE XX

HIGHWAY MILEAGES, EXISTING & UNDER CONSTRUCTION

County & City	Interstate 1970	Interstate Since 1965	Primary 1970	Primary Since 1965	Secondary 1970	Secondary Since 1965
Charles City	0	0	34.72	.26	137.19	1.58
Chesterfield	11.87	0	105.58	3.52	705.19	-103.13[1]
Dinwiddie	26.70	19.64	90.17	2.60	518.24	11.88
Goochland	27.99	27.99	74.35	1.23	274.72	2.17
Greensville	12.57	0	24.69	.02	287.60	2.75
Hanover	14.79	0	94.40	2.11	584.99	28.24
Henrico	29.24	28.23	96.09	-3.01	829.00	0
Isle of Wight	0	0	74.07	4.50	411.96	5.78
James City	5.70	3.32	52.53	2.29	145.69	13.29
Nansemond	0	0	107.65	10.98	436.45	10.73
New Kent	20.00	18.60	59.19	6.00	179.59	3.27
Powhatan	0	0	54.71	4.66	210.77	6.19
Prince George	9.15	0	74.87	- .27	270.58	- .53
Southampton	0	0	84.85	- .08	666.00	5.17
Surry	0	0	48.75	- .05	246.19	5.26
Sussex	0	0	86.55	0	444.44	5.07
York	7.12	0	48.80	4.61	159.91	16.71
TOTAL	165.13	97.78	1200.30	39.37	6508.51	14.43
Gain over 1965		145.2%		3.39%		0.22%
Ave mi/yr 65-70		19.56		7.87		
			Urban Extended		Other Streets	
Chesapeake	15.54	1.94	102.41	-2.67	444.98	-10.21
Colonial Hts.	3.57	0	3.33	0	53.08	17.44
Emporia	.85	0	3.44	0	21.18	.84
Franklin	0	0	4.90	.10	27.06	2.46
Hampton	13.54	.92	49.86	9.05	281.56	37.66
Hopewell	0	0	9.51	1.20	88.66	14.83
Newport News	11.79	0	59.07	-1.57	299.00	47.77
Norfolk	18.13	6.88	76.78	5.50	619.46	10.19
Petersburg	4.76	0	12.42	0	96.66	7.41
Poquoson	0	0	8.95	0	25.94	2.42
Portsmouth	5.26	0	27.94	5.00	331.86	54.86
Richmond	14.56	1.50	64.23	14.19	694.71	190.17[1]
Suffolk	0	0	5.74	0	27.90	0
Virginia Beach	2.93	.28	60.58	0	725.90[2]	114.22[3]
Williamsburg	0	0	11.80	0	24.04	1.39
TOTAL	90.93	11.52	500.96	30.80	3761.99[2]	495.45[3]
Gain over 1965		14.5%		6.6%		15.2%
Miles/yr. 1965-70		2.30		6.16		96.37

[1]Annexed to Richmond from Chesterfield
[2]Includes 23.21 miles primary road
[3]Includes 13.61 miles primary road

Source: Mileage Tables, State Highway Systems, Virginia Department of Highways, December 31, 1970 and December 31, 1965

TABLE XXI

VEHICLE REGISTRATION
March 15, 1971 - June 30, 1971

County	Passenger	Other	Total	Over 6/69	1971 People+ Per Vehicle
Charles City	1,649	595	2,244	1.12	2.75
Chesterfield	32,255	8,747	41,002	0.79*	2.00
Dinwiddie	6,548	2,501	9,049	1.13	2.80
Goochland	3,353	1,298	4,651	1.13	2.18
Greensville	2,877	1,463	4,340	0.79	2.17
Hanover	15,405	6,154	21,559	1.16	1.79
Henrico	64,810	13,914	78,724	1.16	2.02
Isle of Wight	5,997	2,584	8,581	1.10	2.14
James City	4,335	1,373	5,708	1.19	3.33
Nansemond	9,241	3,719	12,960	1.14	2.73
New Kent	1,917	961	2,878	1.15	1.87
Powhatan	2,351	993	3,344	1.12	2.33
Prince George	5,973	2,108	8,081	1.22	3.58
Southampton	5,310	2,483	7,793	1.07	2.34
Surry	1,819	915	2,734	1.10	2.13
Sussex	3,364	1,636	5,000	1.08	2.26
York	11,286	3,175	14,461	1.15	2.40
Subtotal	178,490	54,619	233,109		

City	Passenger	Other	Total	Over 6/69	1971 People+ Per Vehicle
Hampton	44,145	8,513	52,658	1.13	2.35
Hopewell	8,847	2,475	11,322	1.08	2.10
Newport News	46,525	9,248	55,773	1.14	2.49
Norfolk	88,053	24,119	112,172	1.11	2.65
Petersburg	12,428	2,864	15,292	1.07	2.32
Portsmouth	36,471	6,409	42,880	1.09	2.53
Richmond	91,279	26,378	117,657	1.15	2.11
Suffolk	4,444	1,440	5,884	0.94	1.61
Williamsburg	4,562	1,062	5,624	1.11	1.60
Colonial Heights	6,806	1,489	8,295	1.13	1.91
Virginia Beach	65,498	13,275	78,773	1.25	2.34
Emporia	1,626	646	2,272	3.30	2.30
Franklin	857	292	1,149	0.64	5.88
Chesapeake	32,848	8,829	41,677	1.13	2.19
Subtotal	444,389	107,039	551,428		
Total	622,879	161,658	784,537	1.11	2.31

*Loss by annexation to Richmond City
+From Appendix G

Source: Division of Motor Vehicles, User Coordination Section, L.F. Towers, Supervisor, 2220 West Broad Street, Richmond, Va.

TABLE XXII

COMPARATIVE ANALYSIS OF ANNUAL FUEL
ESTIMATES BY POPULATION & CONSUMPTION

County	1970 Total Miles of Road	Daily Traffic Volume Vehicular Miles	1970 Population	Annual Fuel[1] Consumption by Traffic Volume	Annual Fuel[2] Consumption Based on Pop.
Charles City	171.91	88,592	6,158	2,309,720	3,240,340
Chesterfield	822.64	1,314,847	76,855	34,279,939	40,441,101
Dinwiddie	635.11	471,911	25,046	12,303,393	13,179,205
Goochland	377.06	292,497	10,069	7,625,814	5,298,308
Greensville	324.86	296,644	9,604	7,733,932	5,053,625
Hanover	694.18	987,896	37,479	25,755,860	19,721,450
Henrico	954.33	1,365,000	154,364	35,587,500	81,226,337
Isle of Wight	486.03	435,189	18,285	11,345,998	9,621,567
James City	203.92	335,807	17,853	8,754,968	9,394,249
Nansemond	544.10	637,406	35,166	16,618,085	18,504,349
New Kent	258.78	341.381	5,300	8,900,290	2,788,860
Powhatan	265.48	156,742	7,696	4,086,487	4,049,635
Prince George	354.60	577,326	29,092	15,051,713	15,308,210
Southampton	750.85	402,217	18,582	10,486,371	9,777,848
Surry	294.94	134,025	5,882	3,494,223	3,095,108
Sussex	530.99	444,038	11,464	11,576,705	6,032,357
York	208.71	465,998	33,203	12,149,233	17,471,419
Total	7,873.94	8,747,516	502,098	228,060,453	264,203,968
				Difference	36,143,515 (15.9%)

[1] 14 mpg
[2] 526.2 gal/person

TABLE XXIII

NON-URBAN
HIGHWAY MILEAGE AND HIGHWAY TRAFFIC

County	Total Interstate, Arterial & Primary Mileage[1]	Vehicle Miles Per 24 Hours[2]	Total Secondary Mileage[1]	Vehicle Miles Per 24 Hours[2]	Total Vehicle Miles Per 24 Hours	Total Road Mileage
Charles City	34.72	57,293	136.19	31,299	88,592	170.91
Chesterfield	99.50	960,342	705.19	354,505	1,314,847	804.69
Dinwiddie	107.76	374,368	518.24	97,543	471,911	626.00
Goochland	96.05	237,837	274.72	54,660	292,497	370.77
Greensville	37.26	235,858	287.60	60,786	296,644	324.60
Hanover	106.84	806,131	584.99	181,765	987,896	691.83
Henrico	123.84	1,266,088	829.00	98,912	1,365,000	952.84
Isle of Wight	73.92	352,936	411.96	82,253	435,189	485.88
James City	46.97	289,972	159.91	45,835	335,807	206.88
Nansemond	97.02	516,496	436.45	120,910	637,406	533.47
New Kent	54.27	318,864	179.59	22,517	341,381	233.86
Powhatan	48.05	118,864	210.77	37,878	156,742	258.82
Prince George	83.75	504,538	270.58	72,788	577,326	354.33
Southampton	84.85	267,594	666.00	134,623	402,217	750.85
Surry	48.75	88,799	246.19	45,226	134,025	294.94
Sussex	86.55	389,853	444.44	54,185	444,038	530.99
York	51.26	383,606	145.69	82,392	465,998	196.95
Independent Cities						
Chesapeake-Virginia Beach (non-urban)					345,000[2]	310.46[1]
TOTAL	1,281.36	7,169,439	5,679.51	1,479,165	8,993,604	8,224.17

[1] Highway Mileage Tables (1970), Virginia Department of Highways, Richmond, Virginia
[2] Individual County Traffic Surveys, Division of Planning, Dept. of Highways, Richmond, Virginia

TABLE XXIV

TRAFFIC POLLUTANTS (Metric Tons)

	Tons/day	Tons/Year	Annual Tons/km^2	Tons/Year km of Hwy.
Planning District Fifteen				
Charles City County	13.07	4,769.91	10.01	44.93
Chesterfield County	193.02	70,514.52	57.58	140.96
Goochland County	42.94	15,672.57	20.94	68.06
Hanover County	145.62	53,149.79	44.04	123.69
Henrico County	200.38	73,139.43	120.47	76.76
New Kent County	50.12	18,293.80	33.32	125.94
Powhatan County	23.01	8,398.65	12.10	52.23
Richmond City	778.61	287,842.50	2,783.23	610.99
Planning District Nineteen				
Dinwiddie County	69.28	25,285.70	19.25	65.04
Greensville County	43.55	15,894.78	20.39	78.83
Prince George County	84.75	38,934.28	42.51	140.56
Surry County	19.66	7,175.90	9.90	39.20
Colonial Heights City	23.05	23,792.44	18.52	72.14
Emporia City	7.26	2,649.63	428.04	167.49
Hopewell City	35.97	13,127.60	448.53	215.29
Petersburg City	80.15	29,255.77	1,259.25	413.75
Planning District Twenty				
Isle of Wight County	63.89	23,318.30	28.22	77.27
Nansemond County	93.59	34,160.35	20.71	103.09
Southampton County	59.05	21,551.59	13.71	46.21
Franklin City	7.58	2,768.90	280.59	139.49
Suffolk City	3.08	1,125.22	214.01	53.85
Chesapeake-Virginia Beach-Portsmouth-Norfolk Corridor	981.95	385,410.00	335.47	288.52
Chesapeake-Virginia Beach-Portsmouth-Norfolk Non-urban	50.65	18,485.79	21.27	95.87
Planning District Twenty-one				
James City County	49.30	17,993.21	46.94	140.03
York County	68.40	24,969.10	79.02	204.11
Hampont-Newport News City	442.46	161,496.14	325.38	377.11
Williamsburg City	18.96	6,918.64	890.42	310.80
Total	3,649.35	1,332,012.75	75.19	

Annual tons per person for 1970 in RICHEL 0.88

TABLE XXIV(CONT'D)

URBAN
HIGHWAY MILEAGE AND HIGHWAY TRAFFIC

Independent City	Total Road Miles	Daily Vehicle Miles
Chesapeake-Virginia Beach-Portsmouth-Norfolk Urban Corridor	2,000.00	6,689,000
Colonial Heights	56.41	157,000
Emporia	25.47	49,450
Franklin	31.96	51,676
Hopewell	98.17	245,000
Newport News-Hampton	689.49	3,014,000
Petersburg	113.84	546,000
Richmond	758.49	5,372,000
Suffolk	33.64	21,000
Williamsburg	35.84	132,000
TOTAL	3,843.31	16,277,126

TABLE XXV

VEPCO POWER DISTRIBUTION BY CUSTOMER (%)[1]

May, 1971	Residential	Commercial	Industrial	Public	% Increase Over 1969
Central Division[2]	30.7	23.9	35.2	10.0	9.4
Eastern Division					
Norfolk District	34.8	23.0	18.6	22.5	8.6
Peninsula District	29.7	19.7	20.3	30.2	3.0
March, 1971					
Central Division	37.3	21.9	30.3	10.4	2.4
Eastern Division					
Norfolk District	39.6	21.7	14.7	22.9	2.4
Peninsula District	34.1	16.8	18.4	30.6	6.2
June, 1971					
Central Division	38.7	22.0	28.9	10.3	1.6
Eastern Disivion					
Norfolk District	42.8	21.1	13.6	21.4	2.2
Peninsula District	38.3	19.9	16.0	25.7	2.2
November, 1970					
Central Division	34.7	23.6	31.7	9.9	11.0
Eastern Division					
Norfolk District	36.8	24.7	15.3	21.3	9.5
Peninsula District	32.0	21.8	18.6	27.7	1.9

TABLE XXV

VEPCO POWER DISTRIBUTION BY CUSTOMER (%)[1] (CONT'D)

September, 1970	Residential	Commercial	Industrial	Public	% Increase Over 1969
Central Division	37.0	24.9	29.9	8.2	10.3
Eastern Division					
Norfolk District	41.1	25.6	12.1	20.1	11.7
Peninsula District	36.5	22.5	17.3	23.8	12.9
July, 1970					
Central Division	34.3	25.8	30.8	9.0	5.4
Eastern Division					
Norfolk District	36.9	26.7	12.8	22.5	1.1
Peninsula District	32.8	22.4	17.3	27.5	1.1

[1]% for resale not calculated
[2]See Fig. 15 for Division & District Boundaries

TABLE XXVI

NATURAL GAS CONSUMPTION (MCF) 1970 BY DISTRIBUTOR AND AREA

Dist.	Area	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
VEPCO	Norfolk Chesapeake, E.1/2 Virginia Beach	1,512,367	1,500,479	1,397,096	1,173,670	690,881	437,913	399,857	378,660	475,427	669,808	868,815	1,093,219
PGC	Chesapeake, W.1/2	64,770	66,109	63,151	48,839	35,007	32,213	29,537	26,553	29,957	33,635	45,108	63,470
	SUB-TOTAL	1,577,137	1,566,588	1,460,247	1,222,509	725,880	470,126	429,394	405,213	505,384	703,443	913,923	1,156,689
VEPCO	Newport News Hampton Williamsburg James City County York	1,007,421	921,842	804,576	655,230	337,974	199,279	176,620	152,734	175,321	201,847	361,708	646,589
SGC	Suffolk City So. portion-Nansemond County	63,563	73,855	73,900	70,731	63,577	59,305	57,330	45,490	55,633	63,766	66,351	63,541
PGC	Nansemond	157	124	125	68	39	37	50	50	54	75	159	240
	SUB-TOTAL	63,720	73,979	74,025	70,799	63,616	59,342	57,380	45,540	55,687	63,841	66,510	63,691
PGC	Portsmouth	517,592	457,776	439,826	344,497	187,859	135,042	133,567	138,131	132,604	148,019	248,330	378,697
	Isle of Wight	8,539	18,108	19,811	17,917	16,203	15,821	15,251	20,732	24,195	29,275	20,570	38,529
RCD	Henrico Richmond Chesterfield	2,050,013	1,640,441	1,635,635	1,006,506	657,496	529,128	535,132	537,335	540,454	810,685	1,295,480	1,785,189
CGD	Chesterfield	170,435	232,366	265,425	225,480	188,345	177,947	201,273	209,308	187,360	214,916	208,858	242,667
	SUB-TOTAL	2,220,448	1,872,807	1,901,060	1,231,986	845,841	707,075	736,405	746,643	727,814	1,025,601	1,505,338	2,027,856
CGD	Colonial Heights	56,402	37,820	35,000	24,473	12,595	8,606	8,927	8,868	8,415	10,758	21,811	32,527
	Emporia	98	72	61	29	14	10	8	7	5	0	14	318
	Hopewell	77,509	63,520	50,683	41,134	25,813	18,353	18,562	16,961	17,409	23,489	38,828	56,548
	Petersburg	267,507	220,831	222,868	160,664	89,257	62,886	66,187	66,932	62,142	103,819	170,285	215,521
	Dinwiddie	11,008	10,017	9,471	8,829	4,303	3,943	3,009	2,590	2,692	3,654	7,025	7,530
	Prince George	35,941	37,990	38,528	29,382	22,175	22,404	23,243	21,224	20,834	31,393	32,963	40,256
	Sussex	16,810	20,339	24,175	19,771	18,867	16,763	16,386	18,680	17,992	22,040	23,340	20,866
	MONTHLY TOTALS	5,342,540	5,301,689	5,077,331	4,518,101	2,350,395	1,719,650	1,684,939	1,665,479	1,750,494	2,367,179	3,410,645	4,685,299

Total Gas Consumption 1970 in RICHEL 39,873,741 MCF (10^3 cu. ft.)

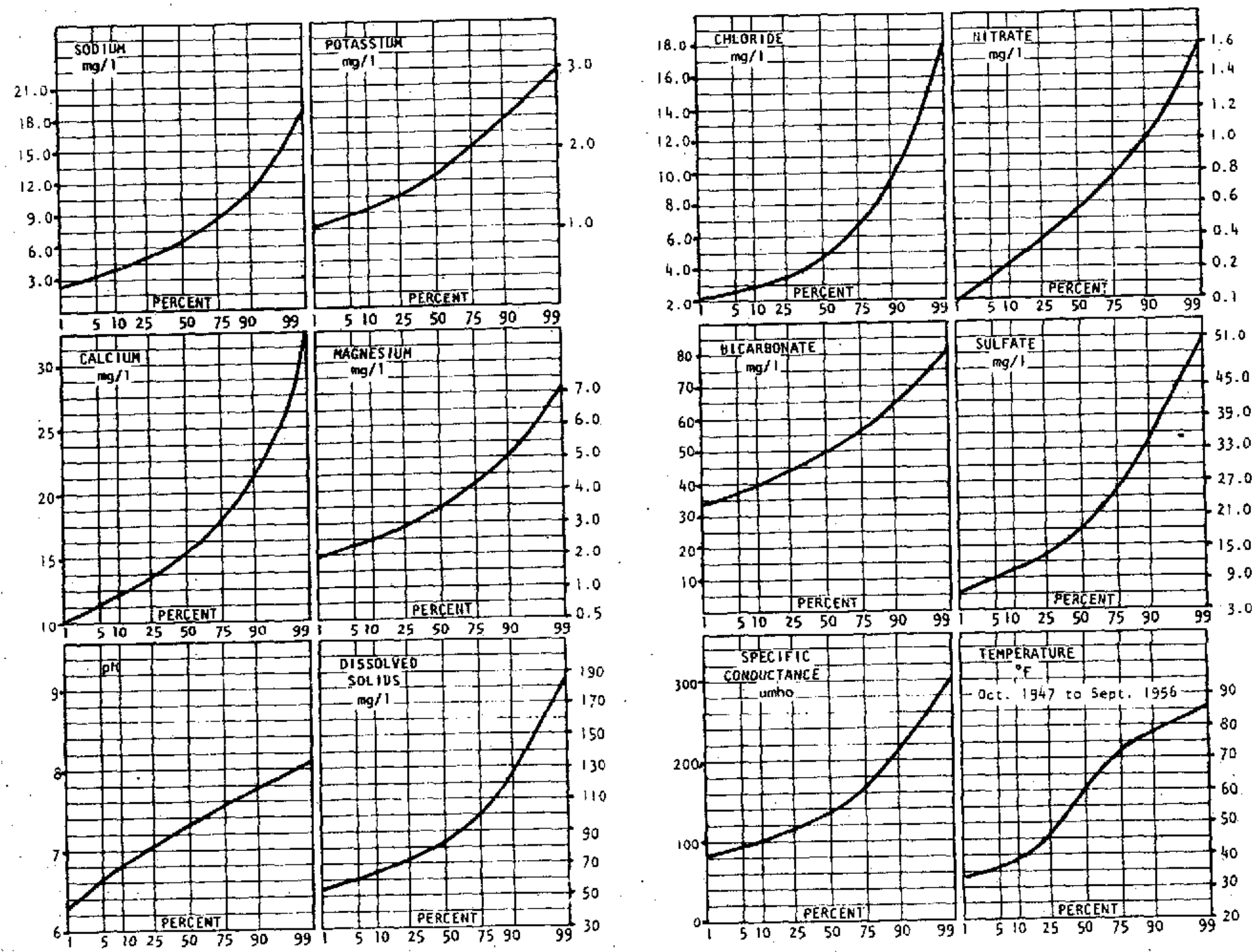
Source: VEPCO and CO-OP Records (Personal Communication)

VEPCO - Virginia Electric & Power Company
PGC - Portsmouth Gas Company
SGC - Suffolk Gas Company
RCD - City of Richmond Gas Distribution
CGD - Commonwealth Gas Distribution Company

TABLE XXVII

JAMES RIVER BASIN

Chemical Analyses of James River Station Number 2-0375 near Richmond, Va.
Period of Record - Oct. 1945 to Sept. 1956



PERCENT OF OBSERVATIONS HAVING VALUES EQUAL TO OR LESS THAN VALUES SHOWN

Source: VDCED, 1971

TABLE XXVIII

RESERVOIR CAPACITY IN RICHEL

Fig. No.	Reservoir Name	Capacity MG	Safe-Yield MGD	Drainage Area mi.^{2}	Area Acres
1	Falling Creek	302	3.6	54.0	120
2	Swift Creek	5,200	12.0	65.0	1,700
3	Lake Chesdin	11,545	100.0	1,335.0	3,060
	Newport News System				
4	Chickahominy	4,500	-	325.0	600
5	Diascund Creek	3,500	-	36.0	1,200
6	Skiffes Creek	260	1.8	6.0	-
7	Lee Hall	844	4.2	16.0	-
8	Harwoods Mill	910	2.0	8.9	80
	Norfolk System				
9	Little Creek (includes Lake Smith, Lake Taylor, Lake Whitehurst & Lake Wright)	1,980	6.4	13.0	1,134
10	North Landing	441	2.0	12.1	1,426
	Western Branch Group				
11	Burnt Mills	3,428	9.0	25.4	1,126
12	Lake Prince	3,700	10.5	30.2	917
13	Western Branch	6,200	7.0	10.0	2,013
	Portsmouth System				
14	Lake Meade	1,600	-	8.0	512
15	Lake Kilby	750	-	20.0	226
16	Speights Run	475	-	*	208
17	Lake Cahoon	1,700	-	30.0	737
	Williamsburg System				
18	Waller Mill	1,400	-	7.0	75

*Part of Lake Kilby Reservoir

Source: VDCED, 1969

TABLE XXIX

WATER USE PROJECTIONS FOR RICHEL TO THE YEAR 2020

POWHATAN AND GOOCHLAND COUNTIES - Water Supply Sub-Area

Public water supply for the counties in this sub-area is expected to be provided entirely from the James River Basin.

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968				1.0		
1980	24,500	3.4	22,300	3.1	18,500	2.6
2000	49,400	8.3	36,900	6.2	27,200	4.6
2020	86,600	17.1	59,800	11.8	41,300	8.2

CITY OF RICHMOND, CHESTERFIELD, HENRICO AND HANOVER COUNTIES - Water Supply Sub-Area

With the exception of some public water service to parts of Hanover County from the York River Basin, all public water service to the sub-area is expected from the James River Basin.

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968				55		
1980	672,000	93	622,900	86	546,000	75
2000	1,090,000	183	935,400	157	720,000	121
2020	1,880,000	372	1,467,000	290	949,000	188

CITIES OF PETERSBURG, COLONIAL HEIGHTS AND DINWIDDIE COUNTY - Water Supply Sub-Area

Petersburg and Colonial Heights public water service are from the municipal supplies. Dinwiddie County lies partially within the James River Basin.

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968						
1980	74,700	10.3	69,300	9.6	64,300	8.9
2000	116,100	19.5	96,700	16.2	78,700	13.2
2020	170,000	33.7	135,500	26.8	93,600	18.5

CHARLES CITY AND NEW KENT COUNTIES - Water Supply Sub-Area

A portion of New Kent County lies outside the James River Basin. Public water supply in the sub-area is expected to approximate the following:

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968				0.02		
1980	650	0.09	570	0.08	510	0.07
2000	2,800	0.47	2,300	0.39	1,800	0.30
2020	5,700	1.13	4,500	0.89	2,900	0.57

Source: Virginia Department of Conservation & Economic Development (VDCED, 1971)

CITY OF HOPEWELL AND PRINCE GEORGE COUNTY - Water Supply Sub-Area

A portion of Prince George County lies outside the James River Basin. Public water supply in the sub-area is expected to approximate the following:

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968				2.6		
1980	53,000	7.3	50,200	6.9	44,200	6.1
2000	116,000	19.5	83,300	14.0	75,600	12.7
2020	236,000	46.7	189,000	37.5	120,000	23.8

CITY OF WILLIAMSBURG AND JAMES CITY COUNTY - Water Supply Sub-Area

A portion of James City County lies outside the James River Basin. Public water supply in the sub-area is expected to approximate the following:

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968				2.4		
1980	21,800	3.0	21,300	2.9	16,700	2.3
2000	42,300	7.1	34,200	5.8	27,400	4.6
2020	75,700	15.0	60,900	12.1	39,400	7.8

CITY OF SUFFOLK, ISLE OF WIGHT, NANSEMOND, SURRY COUNTIES - Water Supply Sub-Area

Some portions of the counties lie outside the James River Basin. Public water supply in the sub-area is expected to approximate the following:

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968				2.4		
1980	37,600	5.2	34,800	4.8	31,200	4.3
2000	59,500	10.0	49,400	8.3	39,800	6.7
2020	96,000	19.0	76,800	15.2	52,000	10.3

CITIES OF NEWPORT NEWS, HAMPTON AND YORK COUNTY - Water Supply Sub-Area

A portion of York County lies outside the James River Basin. Public water supply in the sub-area is expected to approximate the following:

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968				28		
1980	395,900	55	381,600	53	341,500	47
2000	646,000	109	596,000	100	455,000	77
2020	1,100,000	218	914,800	181	505,000	116

CITIES OF NORFOLK, CHESAPEAKE, VIRGINIA BEACH AND PORTSMOUTH - Water Supply Sub-Area

A portion of the public water supply in this sub-area is provided from outside the James River Basin. Future public water supply needs are assumed to be satisfied entirely from the James River Basin.

Year	HIGH Population	HIGH Withdrawal mgd	MEDIUM Population	MEDIUM Withdrawal mgd	LOW Population	LOW Withdrawal mgd
1968				70		
1980	899,500	124	818,600	113	732,000	101
2000	1,418,000	238	1,133,800	190	875,000	147
2020	2,100,000	415	1,655,100	328	1,055,000	209

TABLE XXX

CROPS SPRAYED OR DUSTED DURING 1964

	For Control of Insects and Disease					For Control of Weeds, Grass or Brush			
	Grain Crops	Hay Crops	Vege-table	Fruits/ Nuts	Seed & Other Crops	Corn	Small Grain	Other Crops	Pasture & Range
Charles City	1,021	-	-	-	1,190	4,271	1,720	2,360	130
Chesterfield	34	200	63	38	186	1,537	66	12	10
Dinwiddie	459	72	50	4	2,471	1,878	24	1,048	30
Goochland	450	368	120	10	73	1,050	-	30	-
Greensville	867	6	-	5	7,718	2,362	48	5,288	238
Hanover	1,155	494	443	45	535	4,761	395	326	48
Henrico	93	521	87	-	534	821	290	224	25
Isle of Wight	2,655	125	72	-	10,031	11,837	1	4,029	210
James City	212	35	283	-	-	681	-	200	-
Nansemond	4,739	35	843	-	12,223	11,588	928	7,152	36
New Kent	688	-	421	-	386	5,479	342	1,008	26
Powhatan	26	538	-	6	59	810	-	-	-
Prince George	1,514	255	-	10	1,910	5,644	216	3,813	14
Southampton	1,591	45	277	-	22,812	16,247	-	11,714	155
Surry	726	-	-	28	6,715	4,298	10	2,487	115
Sussex	815	-	-	5	12,459	6,899	-	6,671	20
York	254	120	341	10	117	886	30	59	-
Chesapeake	141	-	1,273	5	7,945	13,930	324	2,956	-
Total	17,444	2,814	4,273	166	87,364	94,979	4,394	49,377	1,045

Source: U.S. Department of Commerce, 1964 Census of Agriculture

TABLE XXXI
ANIMAL CENSUS*

	Hogs	Cattle	Dairy	Sheep
Charles City	4,100	2,200	300	100
Chesapeake	5,700	6,000	1,100	150
Chesterfield	2,300	4,500	700	150
Dinwiddie	17,800	8,300	1,300	100
Goochland	6,700	11,400	1,200	100
Greensville	15,200	3,300	200	150
Hanover	7,100	16,000	2,300	300
Henrico	3,500	5,500	1,400	50
Isle of Wight	30,200	6,300	400	450
James City	2,800	800	200	50
Nansemond	40,000	4,500	400	250
New Kent	5,000	1,700	200	200
Powhatan	2,700	9,000	2,600	100
Prince George	14,500	4,500	500	50
Southampton	77,400	11,000	500	400
Surry	25,300	2,600	200	450
Sussex	30,000	4,500	500	50
Virginia Beach	21,900	4,500	1,100	100
York	700	1,300	700	50

*D. J. Burnette, Extension Agent, Farm Management, Cooperative Extension Service, VPI, Extension Division, 139-C Baker St., Emporia, Virginia 23847. All estimates are for 1970 except hogs which are for 1969.

TABLE XXXII

SOLID WASTE COLLECTION RECORDS*

	1971						1970					
Street Cleaning (in yds.^{3})	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Push carts	134	138	144	180	135	124	116	96	92	120	92	92
Collection by hand	2,052	1,764	1,812	2,666	1,350	536	964	828	784	1,424	1,484	2,340
Motor sweeper	1,362	1,532	1,623	2,090	1,632	1,513	2,480	2,036	2,144	3,800	4,081	2,757
Trash & Garbage Collected (in tons)	13,911	10,629	19,257	25,690	20,246	18,449	14,323	11,463	11,224	13,509	10,748	11,368
Burnable	2,743	1,885	1,910	2,914	1,910	2,245	3,221	2,511	2,552	2,842	1,984	2,067
Non-burnable	407	28	89	1,094	3,413	2,926	2,926	1,114	976	1,033	696	321
Mixed	10,761	8,716	17,258	21,682	14,923	13,278	8,651	7,838	7,696	9,634	8,068	8,980

*City of Norfolk
Street Cleaning Division
237 East Princess Anne Road
Norfolk, Virginia

TABLE XXXIII

HENRICO COUNTY POPULATION

AND SOLID WASTE CALCULATIONS

POPULATION[1]		SOLID WASTE[2]		
Year	Total	Fiscal Year	Tonnage	lbs./day/person
1970	154,364	1970-71	96,435	3.4
1969	120,439	1969-70	75,914	3.4
1968	111,392	1968-69	64,800	3.1
1967	105,097	1967-68	55,822	2.9

[1]Estimates of the Population of Virignia Counties and Cities, Sara K. Gilliam, Bureau of Population and Economic Research, Graduate School of Business Administration, University of Virginia (issued each November with population estimates as of July 1 for that year).

[2]William S. Dewhirst, Director of Public Utilities, County of Henrico (personal communication dated December 1, 1971).

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